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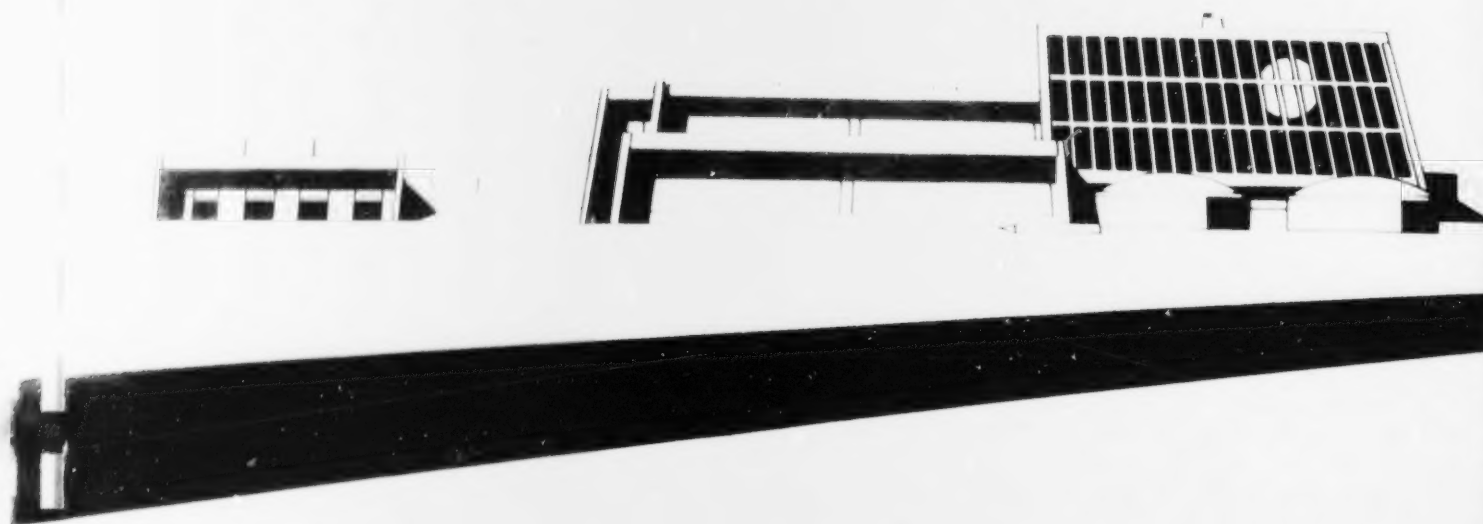
INTERMEDIATE REPORT

Integrated Energy Systems Monitoring
Municipal Wastewater Treatment Plant

WILTON, MAINE

CONTRACT NO. 68-03-2587

MAY, 1980



WRIGHT • PIERCE architects / engineers

June 16, 1980
W-P Project No. 4795

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Dear Mr. Villiers:

We are pleased to submit our intermediate report "Integrated Energy Systems Monitoring, Municipal Wastewater Treatment Plant - Wilton, Maine" (Contract 68-03-2587) which presents the results of our data gathering and analysis effort through March 1980.

The results and our conclusions are presented in the report, so I will not repeat all of them here. Some energy subsystems, notably the heat pump, performed as well or better than expected. Others, particularly the active solar system, performed less well. Data on the performance of the digester gas system is inconclusive due to significant under-loading and difficulties in startup resulting in limited data available under steady state conditions.

There are two significant conclusions (or hypotheses, since the data base is so limited) which can be drawn from our work. The first is that traditional methods for calculating the projected efficiencies of active solar systems are grossly inaccurate and new procedures must be developed. Traditionally, design performance efficiencies of active solar systems are calculated from instantaneous collector efficiency data under seasonal or monthly conditions. Using this method, we calculated an overall projected efficiency of 49 percent for the solar collector array in Wilton. Despite having insolation levels 13.8 percent higher than the ASHRAE estimates used for design, the overall solar array efficiency actually measured was 23 percent. While design, site specific, maintenance and instrumentation factors may have accounted for part of this lower efficiency, the overriding cause appears to be the response of active solar collectors to actual weather conditions and the lack of an accurate calculation procedure to simulate this interaction. Instantaneous collector efficiencies are useful in comparing different types and manufactures of collectors under similar steady state conditions,

Portsmouth, NH
Lowell, MA
Caribou, ME

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but in designing an active solar heating system, a more accurate method must be developed to simulate the actual interaction between day-to-day weather conditions and collector response and performance. Depending on weather conditions, a large percentage of incident solar radiation may be of too low an intensity to collect. During the ten months of full-scale monitoring in Wilton, the actual solar collector performance was less than half that projected. Obviously, this significantly impacts cost-effectiveness.

The second major significant conclusion drawn from our work in Wilton is more tentative and, therefore, may require further study. It is of such importance that we feel it must be presented here, if perhaps with a caveat that it is based on limited actual performance data. That is that while heating of anaerobic sludge digesters may very well be the most cost-effective application for solar heating technology in wastewater treatment applications, it is not absolutely cost-effective. Because of the low overall actual performance efficiencies of the solar collector system discussed above, the payback on the solar equipment is much longer than projected. We feel that reason alone is sufficient to rule out solar heating as a method of justifying anaerobic sludge digestion in plants which are too small to support anaerobic digestion as a sludge stabilization process. If the digesters cannot be justified on their own, the addition of solar energy will not make them more cost-effective. On larger facilities which can produce enough methane gas in the anaerobic digesters to support their heating requirements, the addition of solar heating is not cost-effective, because there are more cost-effective ways to heat the digesters either directly or indirectly with the digester gas produced. Digester heating can be accomplished with the gas directly by burning it in a boiler or indirectly by recovering heat off internal combustion engines fueled by methane, driving electric generators to produce electricity or powering process equipment (replacing electric motors). More energy is recoverable in the form of heat off the engines than is produced in either mechanical or electrical power. If the digesters produce enough gas to justify the capital expenditure for gas-driven engines then enough heat can be recovered off these engines to heat the digesters. Therefore, solar heat is not cost-effective because it is not necessary.

Neither of these main conclusions nor the other lesser conclusions drawn from our work have had enough data developed to prove them conclusively. Therefore, we are suggesting areas for further study to either bear out or disprove the conclusions we arrived at in this interim report. While we are quite sure we are correct in saying that solar heating of anaerobic digesters is not absolutely cost-effective, there may be political, institutional, or regulatory conditions which may require that solar energy be used in wastewater treatment plants to some degree regardless of absolute cost-effectiveness. Therefore, we suggest that further study be done into the most cost-effective application of solar technology. Areas of study would include:

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1. Direct digester heating;
2. Solar heat pump technology;
3. Alternative solar collector designs and system configurations;
4. Continued monitoring of the Wilton system to compare it against these other alternatives.

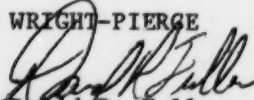
Another area which should be studied, again to determine the most cost-effective application for solar heating of anaerobic digesters would be to study solar applications with different digester sizes to determine if there is a range of sizes for which solar is most cost-effective and to determine if this range varies with different alternative solar designs discussed in the preceeding paragraph.

The data collected on the performance of the anaerobic digesters in Wilton is very limited at this point because the digesters did not reach operational steady state conditions until March 1980. We have continued to collect data and have used data past the April 1 cutoff date in this report. We feel that it is very important to continue to monitor the digester performance and to collect data in Wilton. In addition, the Town has requested from EPA through its open Step 3 construction grant that a gravity sludge thickener be constructed to assist in digester operation. The thickener will help in many areas, all of which would be of assistance in the continuing monitoring program. It would produce thicker sludge going to the digester, cutting down heating requirements and improving performance. It would enable the plant operator to have better control over his sludge handling operation. It would allow for better control of digester supernatant and would enable us to add supplemental feed to the digester to simulate full capacity operation. The addition of this sludge thickener would make it even more useful to extend the monitoring of the digester system in Wilton.

We look forward to a meeting with you and other key EPA/DOE personnel in Cincinnati on Tuesday, June 24 at 9:00 am. We feel it is vitally important that we have this opportunity to personally review our work with you and to discuss our conclusions and proposed areas for further study. We know that EPA is contemplating funding other solar assisted anaerobic digestion plants through the Innovative/Alternative Technology aspects of the construction grants program. If our conclusions are correct, our work in Wilton will have significant impact on the viability of these projects and others now being planned.

Very truly yours,

WRIGHT-PIERGE


David R. Fuller
Project Manager

DRF:mb
Enclosure

EPA - CI-77-0198
May 1980

INTEGRATED ENERGY SYSTEMS MONITORING
MUNICIPAL WASTEWATER TREATMENT PLANT
WILTON, MAINE

Intermediate Report

by

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FORWARD

Man's dependence on non-renewable energy sources must be reduced while the vital functions of environmental protection and space conditioning are provided. Special emphasis must be directed toward improved conservation, more efficient systems and equipment and the development of alternative renewable energy sources. Wright-Pierce has contributed toward these goals through design and studies in

- Biomass fuels development
- Solid waste incineration and heat recovery
- Active and passive solar systems
- Conservation for industrial, commercial and institutional facilities

The integrated energy systems monitoring of the municipal wastewater treatment plant in Wilton, Maine measures the effectiveness of various conservation techniques and the use of renewable energy. Active and passive solar, effluent heat recovery, exhaust air and cooling jacket heat recovery and digester gas production are monitored as an integrated municipal wastewater treatment system. The performance of each under varying weather conditions are evaluated and the relative cost effectiveness determined.

George Barnes
President
Wright-Pierce A/E

ABSTRACT

This project was initiated to monitor the performance of several alternative energy systems installed in the municipal wastewater treatment plant in Wilton, Maine. These systems include: active and passive solar, effluent heat recovery, digester gas generation, air-to-air heat recovery and electricity generation using digester gas. The plant has been operational since September of 1978.

To accomplish the monitoring, an instrumentation system has been installed and data collected since the end of May 1979. This instrumentation system includes: solar pyrometers, hydronic BTU computers, electrical and gas meters, a weather station and numerous temperature transmitters. Data for the solar and digester systems are available in both digital and analog forms.

The primary objectives of the project are to:

1. Determine the effects of weather upon systems performance.
2. To establish how much energy is used and/or produced by each system and its contribution to the various process and building requirements.
3. To determine the cost-effectiveness for each system.
4. To review possible design and operational problems for improved performance.

This report is based on data collected from June 1, 1979 to April 1, 1980 with digester gas production monitoring available during a two-week period in April. The information from the ten month data period can be summarized as follows:

1. Solar Insolation:
 - a. Clear day solar insolation levels were 13 percent above ASHRAE estimates.
 - b. The mean percentage of possible sunshine was 15 percent above the nearest ASHRAE estimate available.
 - c. The average incident solar radiation was 37.3 percent above that estimated.
2. Active Solar System:
 - a. The active solar system produced 116.5 MBTU of usable energy.
 - b. The peak instantaneous collector efficiency reached a high of 66 percent in March.
 - c. The overall annual efficiency of the active solar system was 23 percent (usable energy produced/incident energy).
3. The Passive Solar System:
 - a. The passive solar system produced 52.7 MBTU of usable energy.
 - b. The peak noon transmissivity reached a high of 57 percent in January.
 - c. The average annual transmissivity was 32 percent.

4. The Effluent Heat Pump:
 - a. The total heat produced by the heat pump was 309.8 MBTU.
 - b. The peak coefficient of performance (COP) was 4.0 in August.
 - c. The average COP was 2.9 with a weighted average COP of 2.8.
5. The Generator Heat Recovery system produced a total of 7.9 MBTU. Operation was minimal due to a lack of digester gas.
6. Digester Gas System:
 - a. The digesters produced gas at an average rate of 1100 scf/day as monitored in March and April 1980.
 - b. Problems in the digester gas system and the monitoring instrumentation prevented the collection of sufficient data for any meaningful evaluation.
- 7 Exhaust Air Heat Recovery
 - a. The air-to-air heat exchanger produced the equivalent of 55 MBTU.
 - b. The instantaneous efficiency reached 67 percent in February.

As indicated, there are insufficient data from which to draw meaningful conclusions on the performance of the digester gas system. The data collected for the remaining systems, however, do lead to the following conclusions:

1. Solar system instantaneous efficiencies, when applied to clear day insolation levels and the mean expected percent sunshine, may lead to an overly optimistic evaluation of the actual long-term performance. These losses are related to the system threshold insolation intensity and the random weather patterns. It would, therefore, appear that computer simulation, using averaged hourly weather data and system performance criteria, is required to accurately estimate the long-term efficiencies. Moreover, since the threshold intensity level is predominantly affected by the difference in the average collector fluid and ambient temperatures, the long-term efficiency may be significantly reduced in the northern climates.
2. The effluent heat pump has proven effective under rather severe weather conditions.
3. The passive solar panels were effective during the monitoring period, which should be noted as having higher than anticipated percent sunshine and reduced snow cover.
4. The exhaust air heat recovery system was cost-effective while generator cooling loop recovery was not cost-effective due to low usage.

The evaluation of the performance of the various energy systems in Wilton, their construction and operating costs, and evaluation of the relative cost-effectiveness of the "Wilton design" applied to other wastewater treatment facilities of various capabilities has led to the formulation of a hypothesis which, although not conclusively proven through this work, has much evidence to support it. That is, that solar thermal energy collection combined with anaerobic sludge digestion for the purpose of producing a net excess of digester gas be used as a fuel is not cost-effective, regardless of size or location of the facility.

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ABBREVIATIONS AND SYMBOLS

CFM	Cubic Feet Per Minute
BTU	British Thermal Unit
SCF	Standard Cubic Foot
KWH	Kilowatt Hour
BTUH	British Thermal Units per Hour
I	Incident Solar Radiation
A	Area
U	Heat Transfer Coefficient
MBTU	BTU x 10 ⁶
OAT	Outside Air Temperature
BHP	Brake Horsepower
HV	Heating and Ventilating
EF	Exhaust Fan
DHW	Domestic Hot Water
GWT	Ground Water Temperature
TSP	Total Static Pressure ("w.c.)
"w.c.	Inches of Water Column (Gauge)
PF	Power Factor

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SUMMARY

The Wilton, Maine Wastewater Treatment Plant heating and digester systems were monitored for the period from June 1, 1979 to April 1, 1980. The heating system consists of active and passive solar systems, an effluent-to-water heat pump, a digester gas boiler, an air-to-air heat exchanger, and a generator heat recovery system. The digester system consists of primary and secondary digesters and high and low pressure gas utilization and storage systems.

The scope of work of this project was to determine the actual operating parameters of each system then to relate these parameters as to how they affected the other related systems. The effect of varying weather conditions on these systems was to also be investigated.

The monitoring system was designed and installed based on anticipated results. Generally, the equipment was of sufficient sensitivity and range to provide valid results. However, various problems developed with some equipment during the monitoring period and data was lost while repairs were made (see Chapter 7).

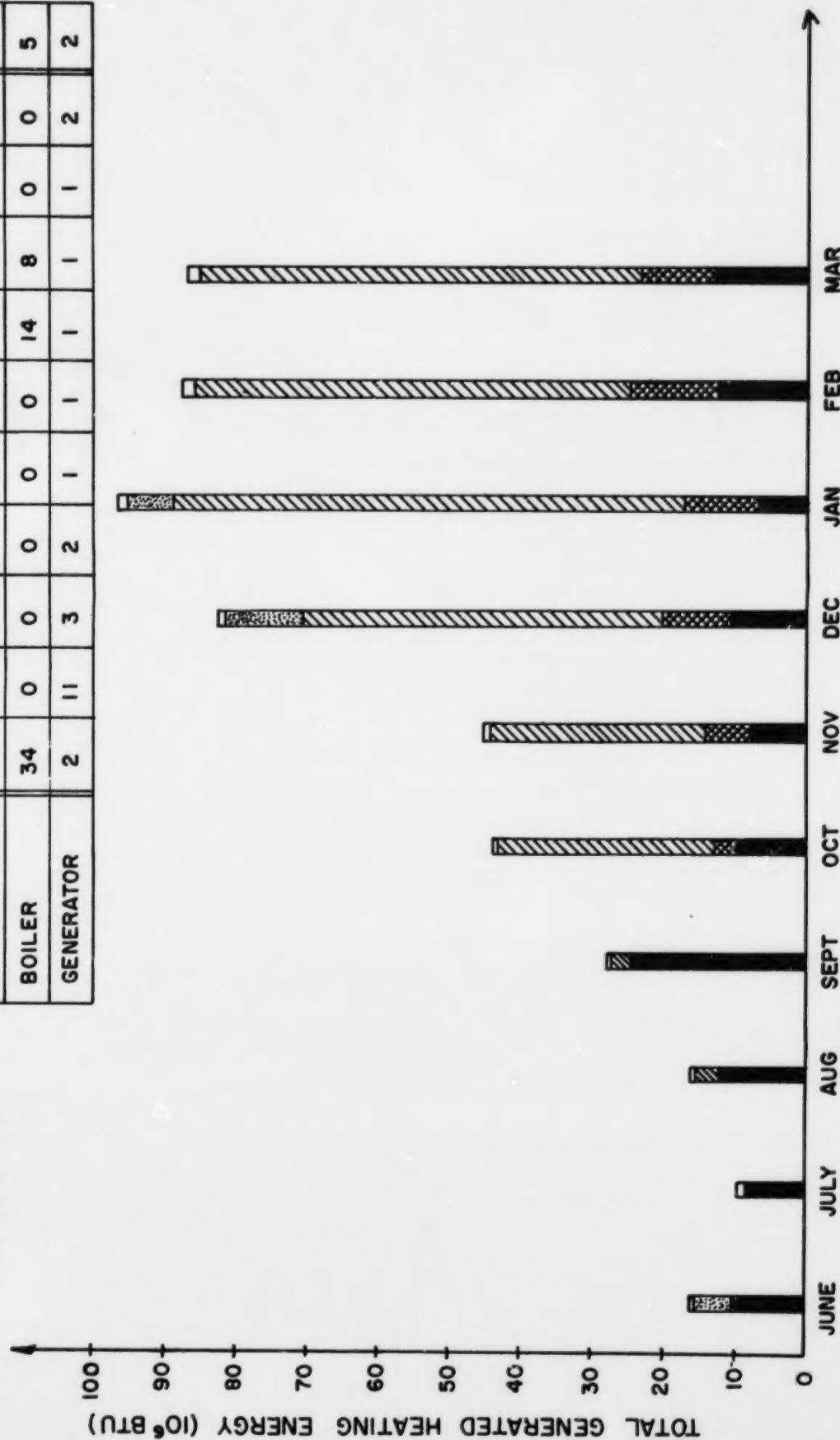
With the available data, each major component of the heating system is analyzed and evaluated for its energy and cost effectiveness. The digester gas production rates have been evaluated using the limited data available. Substantially more data are needed and the performance optimized before any accurate conclusions may be reached. The gas utilization system, a part of the digester system, has not been further analyzed due to problems experienced in the operation of the system (see Chapter 7).

Figure 1.1 illustrates the total energy produced by the heating system according to each component's contribution. This figure does not include the electrical contribution made by the DHW electrical immersion heater. (The total source contribution, including the electrical DHW heating, is tabulated in Table 5.3 on an energy basis.) Table 1.1 summarizes the energy and cost effectiveness for the various systems (see Chapter 6).

ENERGY SOURCE PERCENT CONTRIBUTION

SOURCE	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	TOTAL
ACTIVE SOLAR	61	89	75	88	23	17	13	7	14	15	23
PASSIVE SOLAR	0	0	0	0	6	15	12	11	15	12	10
HEAT PUMP	3	0	22	10	70	67	60	73	70	71	60
BOILER	34	0	0	0	0	0	14	8	0	0	5
GENERATOR	2	11	3	2	1	1	1	1	1	2	2

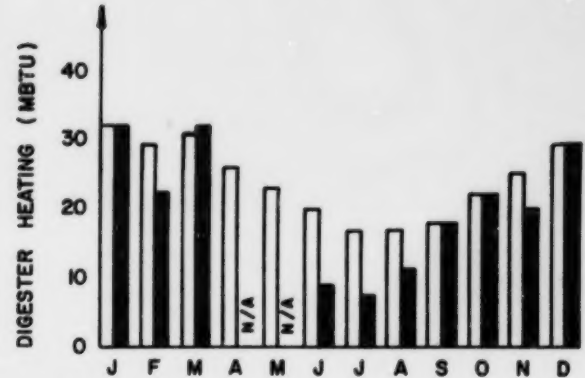
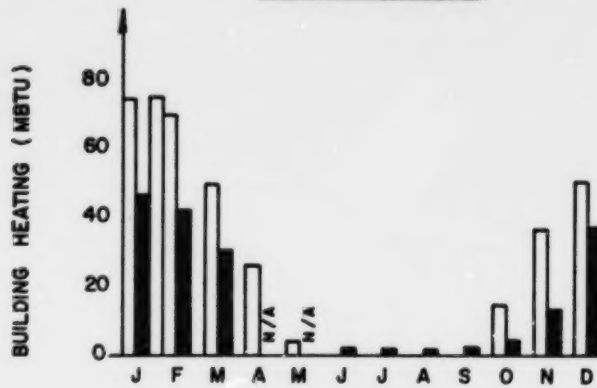
- ACTIVE SOLAR
- PASSIVE SOLAR
- HEAT PUMP
- BOILER
- GENERATOR



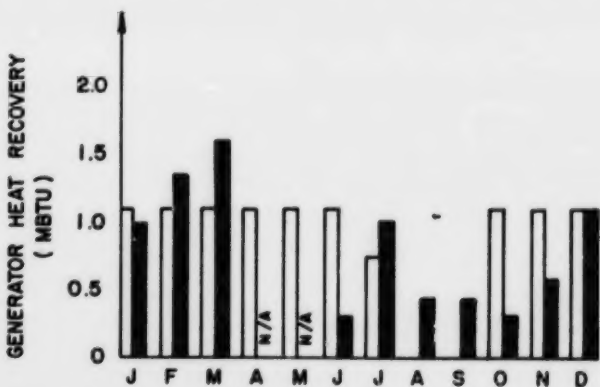
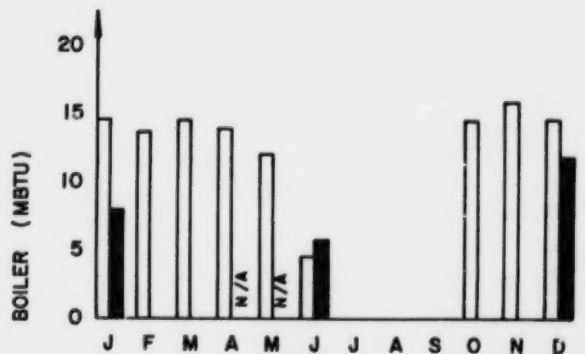
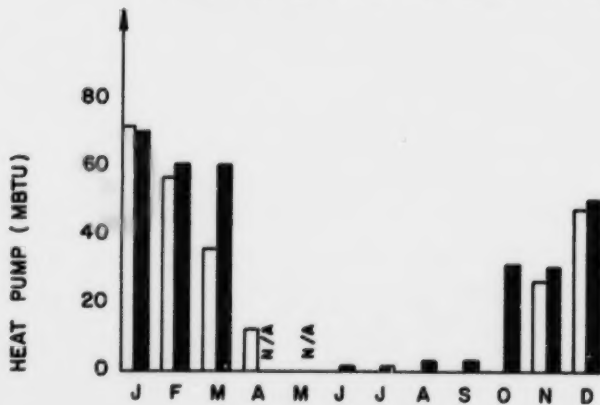
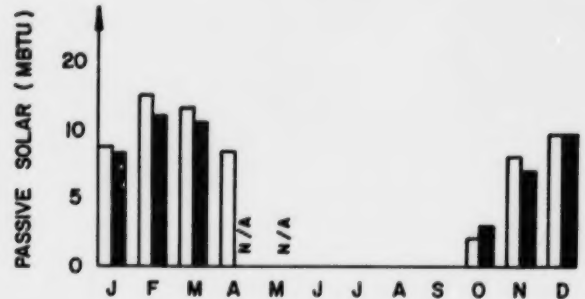
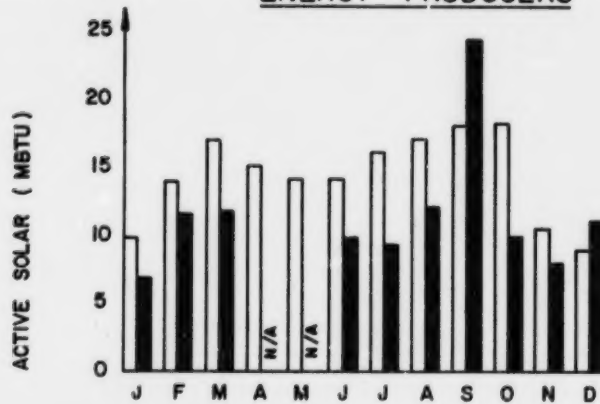
TOTAL ENERGY SOURCE CONTRIBUTIONS

FIGURE 1.1

ENERGY USERS



ENERGY PRODUCERS



 ESTIMATED ENERGY
 ACTUAL ENERGY

NOTE: SUMMER BUILDING HEATING LOSSES DUE TO CIRCULATION LOSSES.

ENERGY
USAGE / PRODUCTION
SUMMARY

TABLE 1.1
ENERGY AND COST EFFECTIVENESS SUMMARY

<u>Component</u>	<u>Energy Output/ Input Ratio (1)</u>	<u>Value Output/ Input Ratio (2)</u>	<u>Simple Payback (3) (Years)</u>
Active Solar	11.5	5.5	54
Passive Solar	32% ⁽⁴⁾	N/A	30
Heat Pump	2.90	1.4	18.7
Generator Heat Recovery	113	61	48
Air-to-Air Heat Exchanger	9.0	4.3	12.2
Digester Gas Production	0.58	0.55	N/A

¹The Energy ratio is the total energy produced divided by the energy input required.

²The Value Ratio is the dollar value of the energy produced divided by input energy cost.

³The Simple Payback is the installed cost divided by the net savings. No inflation factor for replaced fuels was applied.

⁴Actual average monthly solar radiation transmitted through panels from June 1, 1979 to April 1, 1980 (see Chapter 5).

From Table 1.1 it can be seen that each of the measures, except for the Digester Gas Production, was a net energy producer and net cost saver. However, the payback periods generally were greater than are economically justifiable. Each measure will now be reviewed with comments and recommendations concerning, energy and cost effectiveness, the payback periods and how they might best be optimized.

ACTIVE SOLAR

The active solar system has been monitored for a 10 month period beginning in June of 1979 through March of 1980. Table 1.2 summarizes the collected data as follows:

1. Recorded clear day insolation levels were consistently above ASHRAE estimates with an average difference of 13.8% (Item 9).
2. The recorded percent of possible sunshine was 60% versus an average of 52% predicted. This is consistent with the unusually low precipitation levels experienced.
3. The average incident solar radiation was 37.3% above that estimated (Item 11).
4. The total solar energy collected as 116 MBTU (Item 16) which was 64% of that estimated.
5. The overall solar system efficiency, efficiency being, the net energy collected divided by the total incident available, was 23% (Item 15).

An overall efficiency of 23% is significantly lower than that anticipated. A great deal of effort was spent in investigating the reasons which were presumed to be one or more of the following:

1. Data/Instrumentation error.
2. Collector Heat Loss Factor
 - a. Inadequate thermal isolation.
 - b. Possible convective losses between the absorber plate and the rigid insulation.
3. Collector Heat Transfer Losses
 - a. Air within the fluid loop.
 - b. Effect of the Glycol solution.
4. Control sequencing and response.
5. Collector efficiency losses due to dirt accumulated during construction.

While all of these factors (excluding the first) certainly contribute to the solar system performance, the overriding cause appears to be the combination of all of them coupled with actual weather conditions and the lack of an accurate calculation procedure to simulate this interaction.

There is obviously a significant difference between instantaneous collector efficiency and day-long or, more importantly year-long collector efficiency. Instantaneous efficiencies are useful in comparing various types of collectors under similar steady state conditions, but tend to create a misleading picture of the efficiency of water heating systems operating over long periods.

Table 1.2

MONTHLY SUMMARY AND
SOLAR UTILIZATION

1	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	See Note
2	Days in Month	31	29	31	30	31	30	31	31	30	31	30	31	
3	ASHRAE Clear Day Insolation (BTU/FT ² Day)	1747	2100	2178	2035	1885	1810	1851	1970	2072	1982	1713	1561	A
4	Grimman Clear Day Insolation (BTU/FT ² Day)	1652	2001	2082	1953	1781	1675	1693	1819	1954	1977	1769	1512	B
5	Mean Percent of Possible Sunshine	43	51	53	53	57	62	63	61	58	54	39	38	C
6	Probable Available (4 x 5)	710	1020	1103	1035	1015	1038	1066	1109	1133	1067	690	574	
7	Recorded Average Insolation (BTU/FT ² Day)	1138	1507	1313	--	--	1457	1509	1308	1737	934	856	1040	
8	Recorded Clear Day Insolation (BTU/FT ² Day)	2111	2281	2574	--	--	2011	1801	2350	2311	2295	1994	1862	D
9	Recorded I/ASHRAE I (8 / 3)	1.21	1.09	1.18	--	--	1.11	.97	1.19	1.12	1.16	1.16	1.19	E
10	Recorded Clearness (7 / 8)	54	66	51	--	--	72	84	56	75	41	43	56	N
11	Recorded I/Probable I (7 / 6)	1.60	1.48	1.19	--	--	1.40	1.42	1.18	1.53	.88	1.24	1.81	F
12	Probable Net Collected (BTU/FT ² Day)	313	477	542	494	463	470	523	596	631	589	347	250	G
13	Actual Net Collected (BTU/FT ² Day)	177	337	334	--	--	254	213	321	599	254	202	270	H
14	Net Collected/Probable Net (13 / 12)	.56	.71	.62	--	--	.54	.41	.54	.95	.43	.58	1.08	I
15	Net Collected/Recorded I ₆ (13 / 7 x 100)	15.5	22.4	25.4	--	--	17.4	14.1	24.5	34.5	27.2	23.6	25.9	J
16	Total Solar Produced (10 ⁶ BTU)	7.06	12.56	13.33	--	--	9.77	8.46	12.23	12.47	10.11	7.79	10.74	K
17	Total Heating Load (10 ⁶ BTU)	96.32	87.35	86.76	--	--	16.07	9.47	16.26	27.80	44.15	44.77	82.87	L
18	Percent Solar (16 / 17 x 100)	7	14	15	--	--	61	89	75	88	23	17	13	M
19	Average Daily Temperature (°F)	20	18	30	41	52	62	71	62	54	46	40	25	

A. Solar insolation for the 21st of each month, 44° latitude, 59° tilt from the horizontal, facing due south.

B. Solar insolation for the 15th of each month, 44° latitude, 60° tilt from the horizontal facing 2° west of south.

C. Tabulation derived from "Normals, Means, and Extremes" table in U.S. Weather Bureau publication, Local Climatological Data. 53 percent average using Albany, New York.

D. Actual clear day data recorded for each month.

E. 13.8 percent over probable available insolation.

F. 37.3 percent over probable available insolation.

G. Probable net collected 6x collector efficiency factors.

H. Net collected (water side of solar heat exchanger).

I. 64.2 percent of that estimated.

J. 23 percent of recorded incident solar collected.

K. For 1286 FT² collector surface, 116.5 x 10⁶ BTU/10 months.

L. Heating load includes process, transmission and ventilation loads.

M. 23 percent overall being supplied by solar.

N. Actual average percent of possible sunshine - 60 percent.

In the month of March, for example, approximately 1/3 of the incident radiation was of too low an intensity to collect. In many cases the collector plate temperature never reached a usable or threshold level although considerable insolation was available. An illustration of these losses in long term efficiency is shown in Figure 1.3 for a clear day. The corresponding losses for a cloudy day are obviously greater, particularly if the solar radiation intensity equals the critical, or threshold intensity.

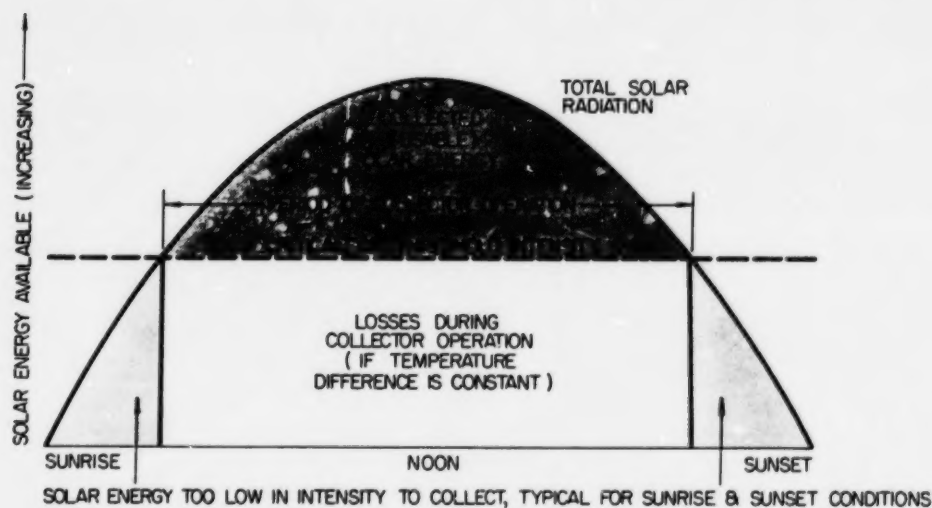


FIGURE 1.3 COLLECTION OF SOLAR RADIATION THROUGHOUT THE DAY

The dominant factor in establishing the threshold intensity level is the temperature difference between the absorber plate and the ambient air. If this difference is minimized by either a warmer climate or a cooler collector fluid, as in the case of a heat pump assisted system, or both; then this threshold level would be reduced and the long term system efficiency improved. For example, in the case of a heat pump/solar system with an average collector fluid temperature of 50°F and an ambient temperature of 75°F, the threshold intensity level would actually be negative, enabling the system to collect heat without solar radiation.

As indicated, the causes were investigated for the lower overall efficiency based on the assumption that the estimating procedures were accurate. Numerous alternative procedures were studied with similar inflated results. In the course of the investigation several publications were discovered which included test data for actual solar systems monitored for a one year period. The results of these studies are similar to the findings to date at the Wilton plant. Each of the systems monitored consisted of flat plate collectors, non-selective coating, with 2 glass covers. The first involved a 540 ft.² solar system located in Morton Grove, Ill. This system was monitored in 1975 by the Fluid Handling Division of ITT and had an overall efficiency of 21% (See reference 8). The second system was located in Fort Collins, Colorado. It was monitored for one year by the Solar Energy Applications Laboratory at Colorado State University and had an overall efficiency of 19% (See reference 9).

PASSIVE SOLAR

The passive solar array is built into the wall at two levels. Solar radiation passes through the array providing both heating and lighting in the Clarifier Room. Each bank of panels has an overhang which tends to shade them during the summer months when heating is not required. Operable windows cool the space when the temperatures become excessive. The energy collected during these times is lost and, therefore, not considered useful.

Increasing the transmissivity and/or decreasing the "U" factor would increase the net quantity of collected solar radiation. More would be provided as useful during the winter but more would have to be dumped during the summer. For the panels, varying the ratio of transmissivity/"U" factor and estimating the net energy collected would provide an indication of what a change in that ratio would do to the system. Other factors such as overhangs, and variations in transmissivity with incident angle need be considered also.

For this installation, the variation in overall performance appears adequate, transmissivity increasing during the winter, decreasing during the summer. The overhang is responsible for a decrease in transmissivity during the summer up to a daily average of 14 percent.

HEAT PUMP

The heat pump operating time was greater than anticipated during this period. The COP was quite acceptable during the heating season. The generation of the heating energy gave a net cost savings and the payback period was reasonable. Had the heat pump operating time equaled the projected operating time, the payback period would have been closer to 25 years which is still reasonable.

The actual and projected hours of operation are based on present operating conditions. As the plant flow rates increase and digester gas production increases, the heat pump will be used less with an increasing payback period due to less operation time.

To date, the operation and maintenance problems encountered have been relatively small. A good deal of time, however, has been spent in cleaning the effluent strainers. Records should be kept for several years to determine realistic O&M costs for the system.

GENERATOR HEAT RECOVERY

The generator heat recovery loop operated approximately one half hour per week during the generator exercise period. During part of that time, the recovery loop was not used because the storage tank temperature was warmer than the maximum generator cooling heat exchanger allowed, City water was then used to cool the generator. This condition will arise regularly during the summer when there is a limited heating demand, and the active solar system is able to provide most of the heating required.

The generator could be exercised for longer periods of time during the heating season when digester gas is available.

The generator heat recovery loop has the highest energy output/input ratio, but the payback period is the worst. This is due to the low periods of use being experienced.

DIGESTER GAS GENERATION

The digester gas generation system is, from Table 1.1, an energy and value loser. However, process requirements must also be considered when evaluating this system. The digester is still being optimized and it appears that significant improvement can be realized in this part of the process, resulting in increased gas production per unit of energy consumed. Other options can also be considered such as varying the detention time, temperature, mixing periods, storage of methane, etc.

REFLECTED SOLAR RADIATION

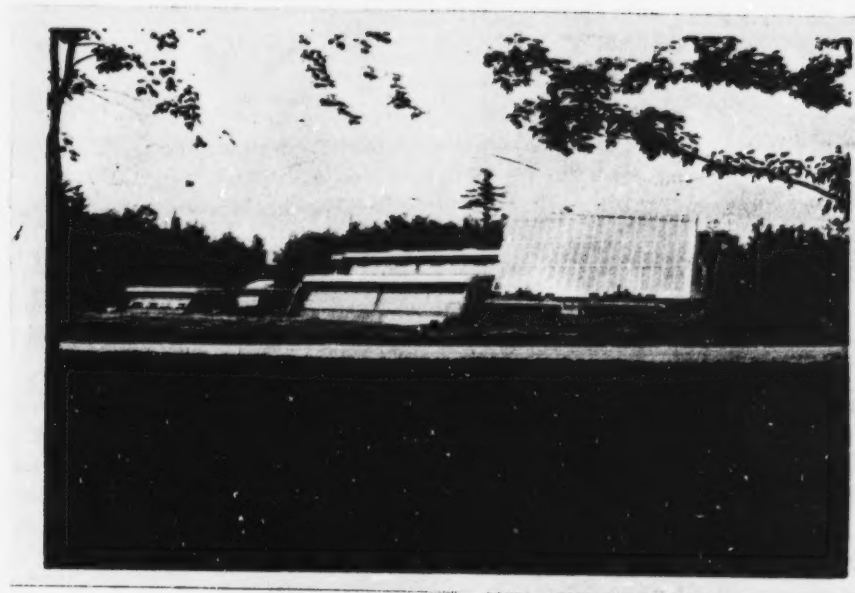
An attempt to measure the magnitude of the ground reflected solar radiation component met with limited success. From Chapter 5, the reflected component for peak nonclear days was within the experimental accuracy of the equipment being used. The average daily reflected component consists of both reflected and some diffuse solar insolation. Thus no meaningful data on the magnitude of the reflected component were gathered. Part of the reason for this was the minimal snow cover experienced during the winter of 1979-80.

ELECTRICAL USAGE

Even with the heat pump operating more and the generator operating less than anticipated, the total electrical usage has been less than the projections of Chapter 4. The reduction for the ten month monitored period is 12.5%.

FACILITY DESIGN

FIGURE 2.1



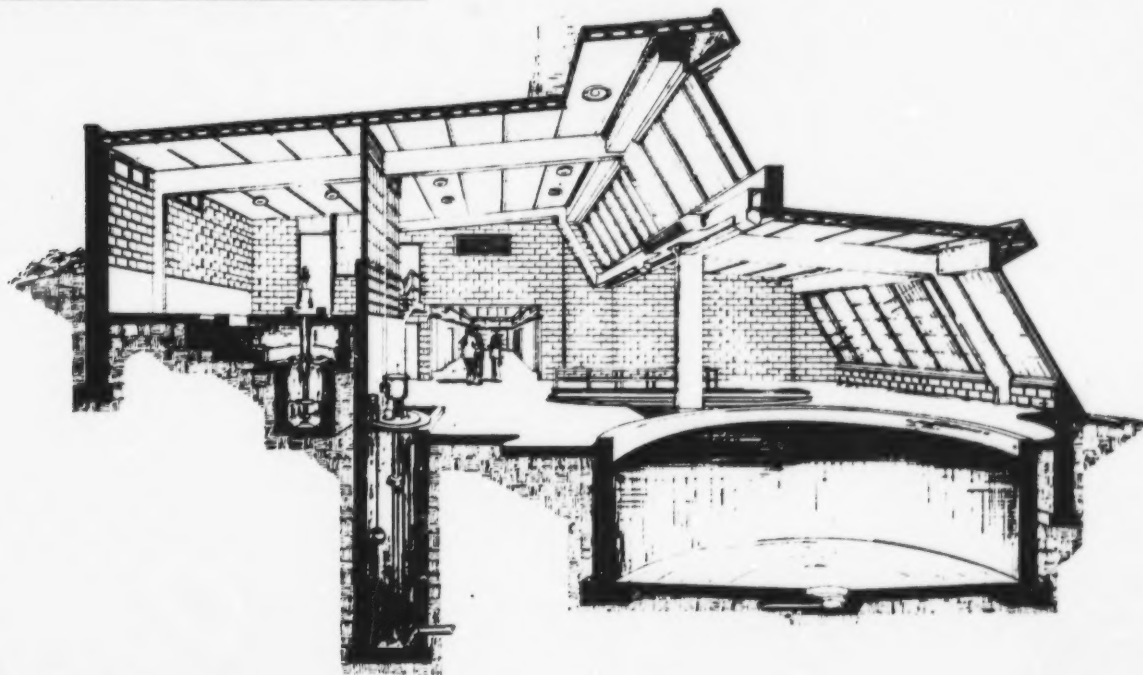
WILTON TREATMENT PLANT

The overall objective of the architectural and engineering design of the treatment plant was to integrate the sciences, creating a totally unified economical project employing complementary systems and building configurations. The latest technological advances were brought into play where applicable. Special emphasis was placed on the reduction of the need for energy. This has been accomplished through the use of alternate energy sources, low energy requiring process equipment, and a combination of good engineering and architectural design principles. Due to Wilton's cold climate, the entire plant is enclosed in two structures. To save on energy, unit processes have been brought close together, while still providing for future expansion. Gravity is used wherever feasible to avoid the use of pumps. The building is well insulated and zoned to enable different rooms to be heated to different temperatures. It is constructed of concrete block and brick with insulation between to provide a large mass which holds the heat at night. The roof is designed to hold snow to provide good natural insulation. The surrounding groundcover of juniper will also hold the snow for insulation. The building is built into a hillside, with little exposure to the north, to minimize the exterior surface. This results in lower demands for heating, lighting and system loads.

The most significant innovation which reduces the requirements for "off site energy" is the application of solar energy, which for the first time is used in a sophisticated manner as an integral part of the wastewater treatment process. The enclosing structures are oriented southward to achieve maximum value from the sun's direct energy through both passive and hydronic solar energy collection devices. Passive solar collection is achieved through the use of fiberglass panels which let solar heat into the process rooms of the plant to directly heat the air, without letting the heat out. Black metal solar collector panels, set at a 60° slope, form the south roof of the treatment plant. An anti-freeze solution is pumped through these panels and heated to 120° to 140°F by the sun. Although this solar energy is used to heat the building and the hot water supply, its primary purpose is to provide heat for the anaerobic digesters.

FIGURE 2.2

WILTON TREATMENT PLANT SECTION



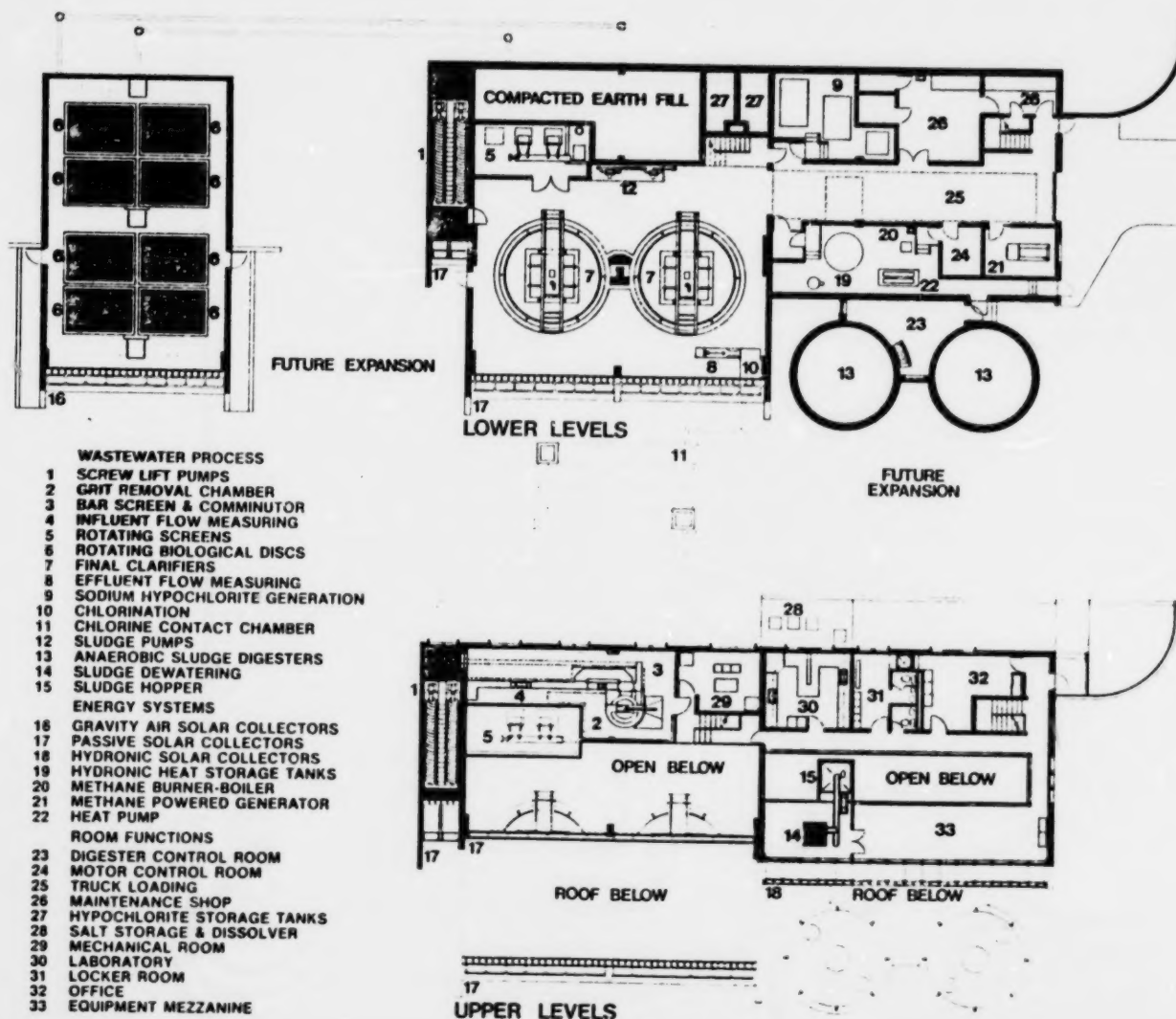
TREATMENT PROCESS

Before disposal, sludge is stabilized in the anaerobic digesters which must maintain steady temperatures of approximately 95°F. Methane gas is evolved as a by-product of this digestion process and traditionally is burned to provide heat for the digester. In small treatment plants, such as this one, all the methane would normally be used to heat the digester. None would be available for other purposes, thus a large amount of auxiliary off-site fuel would be required, especially in the winter. The use of solar energy to heat the digesters, therefore, frees the digester gas to be stored for use in heating the building, running the electric generator, and long term storage. This overcomes one of the main problems of solar energy, that of storage. Digester gas is a much more economical material to store than heated water, and it is also much more flexible in its use.

The treatment process and energy systems are coupled to produce more alternate sources of energy. Maximum excess heat energy, including excess heat from exhausted air, generator coolant, and effluent water is recovered within the building for reuse. The recovery of 60% of the heat from exhaust air in the ventilation system will be used to preheat cold air drawn into the plant. The effluent from the plant normally is discharged at 45° to 50°F, even in the winter, which represents a potentially useable source of heat. By using an electric heat pump, the Wilton plant recovers much of this wasted heat, producing three units of heat energy for every equivalent unit of electrical energy used. Not only does this help heat the building, but the resultant lowering of the effluent temperature prevents thermal shock on the stream, which may happen when relatively warm effluent is discharged to the cold waters of the stream in winter.

FIGURE 2.3

FLOOR PLANS

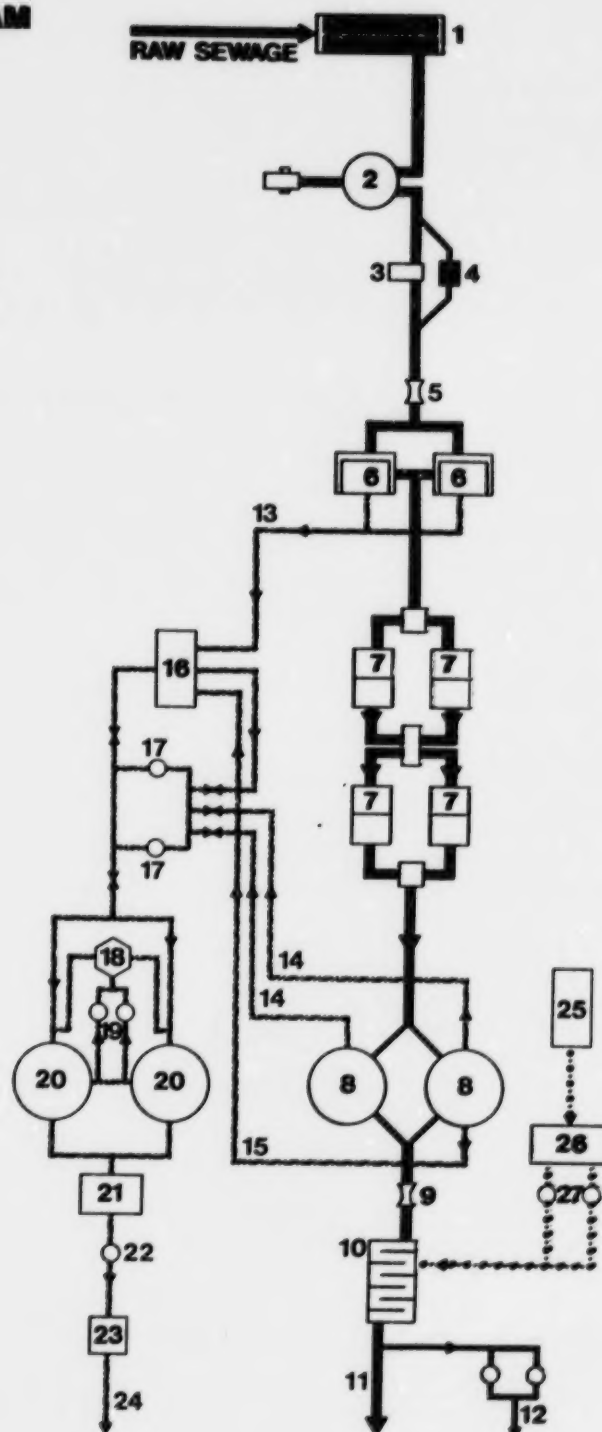


The treatment process has been designed for simplicity of operation and maintenance. Wastewater is lifted into the plant by screw pumps, which use less energy than conventional pumps, and automatically provide variable flow, thus preventing overloading of the treatment processes. The wastewater flow is by gravity throughout the rest of the plant, again conserving energy. Pre-treatment is provided by comminution and grit removal. Gross solids are removed by rotary screens. Secondary biological treatment is accomplished via the rotating biological contactor (RBC) process, which consists of shafts of plastic discs rotating in the wastewater, with biological masses growing on the discs and treating the sewage. This again is a low energy, low maintenance process. Final solids separation is accomplished in clarifiers, from which the solids are combined with the primary screenings and pumped to anaerobic digesters for stabilization before being dewatered and disposed of; and the effluent is disinfected and normally discharged to the stream. The disinfectant is sodium hypochlorite, which is generated on-site electrochemically from salt and water, at a cost competitive to that of purchased chlorine gas, without the safety problems and uncertainty of supply.

FIGURE 2.4

TREATMENT PROCESS DIAGRAM

- 1 SCREW PUMPS
- 2 GRIT CHAMBER
- 3 COMMUNUTOR
- 4 BAR SCREEN BY-PASS
- 5 FLOW MEASURING & SAMPLING
- 6 PRIMARY SCREENS
- 7 ROTATING BIO-CONTACTORS
- 8 SECONDARY CLARIFIERS
- 9 FLOW MEASURING & SAMPLING
- 10 CHLORINE CONTACT CHAMBER
- 11 PLANT EFFLUENT
- 12 SPRAY IRRIGATION
- 13 PRIMARY SLUDGE
- 14 SECONDARY SLUDGE
- 15 SECONDARY SKIMMINGS
- 16 SLUDGE HOLDING
- 17 SLUDGE TRANSFER
- 18 SLUDGE HEATER
- 19 SLUDGE RECYCLE PUMPS
- 20 ANAEROBIC SLUDGE DIGESTERS
- 21 SLUDGE HOLDING
- 22 SLUDGE DEWATERING PUMP
- 23 DEWATERING UNIT
- 24 DEWATERED SLUDGE
- 25 HYPOCHLORITE GENERATION
- 26 HYPOCHLORITE STORAGE
- 27 METERING PUMPS



DESIGN CRITERIA

Quantity of sewage

450,000 gal/day

Influent BOD

200 mg/l (750 lbs/day)

Influent suspended solids

200 mg/l (750 lbs/day)

Effluent BOD

20 mg/l (75 lbs/day): 90% removal

Effluent suspended solids

20 mg/l (75 lbs/day): 90% removal

Sludge quantity to digesters

2500 gal/day at 3.5% solids

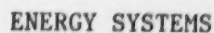
Methane yield

3900 to 4400 cubic feet/day

Methane heat value

600 BTU/CF or 2.3 to 2.6 million BTU/day

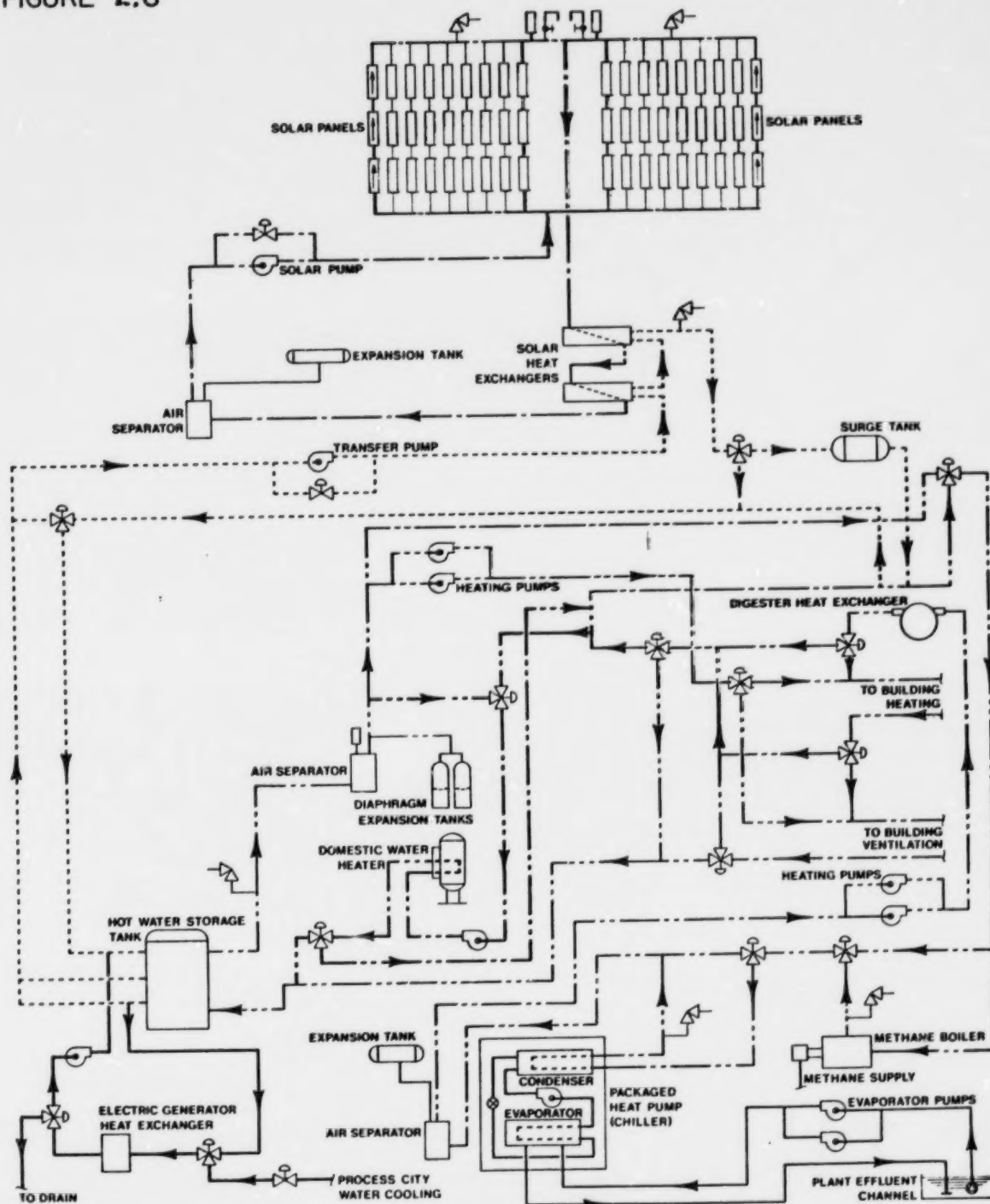
ENERGY SYSTEMS CONCEPTUAL DIAGRAM



The solar energy subsystem is a hydronic type with flat plate collectors 1500 square feet in area, an ethylene glycol/water collection loop, a heat exchanger, and storage systems. The solar collectors should collect between 220 and 260 MBTU per year, while the passive collectors will add another 100 to 130 MBTU per year. Ethylene glycol is circulated through collector plates which are heated from the sun's rays, and this energy is then exchanged to the plant's circulating water system.

The digester/methane subsystem is not especially unique in its function and design; however, the integration with the total system and its role in the energy conserving nature of the facility is unusual. The gas released becomes an important part of the total operation since it is used for the boiler in normal operation, and for the emergency electrical generator when excess gas is available.

FIGURE 2.6



HEATING SYSTEM FLOW DIAGRAM

- GENERATOR HEAT RECOVERY SYSTEM
- ETHYLENE GLYCOL WATER LOOP
- HEAT PUMP EFFLUENT PIPING
- SOLAR ENERGY TRANSFER LOOP
- DOMESTIC WATER HEATING PIPING
- HEATING SYSTEM PIPING
- ⊕ RELIEF VALVE
- ⊕ CONTROL VALVE
- ⊕ AIR VENT
- ⊕ PUMP

ENERGY MONITORING SYSTEM

The objectives of the energy systems monitoring program are to predict, verify, and summarize the performance of the building thermal systems, especially in the digester area, on a totally integrated basis that is not available through predictive analysis of individual components.

These objectives are tied very closely to the basic energy conserving design of the plant itself which is represented in Figure 3.1. Each subsystem is not especially unique in design by itself, however, the integrated subsystems pose complex problems in the interaction of process variables. This is especially prevalent in interaction between energy sources, i.e. solar input, methane boiler, heat pump and energy users, i.e. digesters, building heating and ventilation.

The integration of these subsystems is unique and design has been based on data provided by solar, emergency generator, boiler and digester manufacturers who have detailed knowledge of their system but limited knowledge of the total system. It is in these areas that the system is monitored and data gathered to determine how the system interfaces.

ACTIVE SOLAR SYSTEM

In this subsystem an ethylene glycol water solution is circulated through collector plates which are heated from the sun's rays. This energy is then exchanged to the plant circulating water system. An underlying design premise is to use solar energy whenever it is available, with the use a function of exchanged temperature. The total performance of this subsystem needs to be determined.

Solar insolation is measured (for (1) direct diffuse and reflected and (2) direct and diffuse only) and continuously recorded on a strip chart with an integrated digital output as well. Solar plate temperature and glycol flows and temperatures are also recorded. A hydronic BTU computer will monitor the total heat from the solar heat exchanger for both analog and digital recording. Electrical input to solar pumps are also monitored.

One of the major loads which the solar system will supply is the digester heating, as described in the following section.

DIGESTER

This subsystem again is not especially unique in its function and design, however, the integration with the total system and its part in the energy conserving nature of the plant is unique. The digester gas released becomes an important part of the total operation, as it is used in the gas boiler in normal operation and the emergency generator when excess gas is available.

A determination will be made as to the quality and quantity of gas produced and where it is used. The properties and quantities of the sludge flow in and out of the digester, sludge and digester temperatures and the heating and electrical requirements will be monitored.

EFFLUENT HEAT PUMP

The heat pump is a unique subsystem extracting heat from the effluent and converting it for use in the heated water system. Its interaction will be monitored to verify performance and contribution.

Electrical input and heating output were monitored continuously with digital outputs. Additionally, temperature and pressure drops across the evaporator and condenser and the auxiliary pump electrical usage will be monitored. The unit coefficient of performance will be determined for various conditions.

PASSIVE SOLAR SYSTEMS

Light/heat transmitting panels are employed in this plant. Their contribution to the total plant energy provides useful design data for scaled-up plants.

Solar insolation and solar transmissivity is measured and continuously recorded. Space temperature and heating requirements were also be monitored to give an indication of the massive construction heat storage effect.

WEATHER DATA

All calculations for this plant are based on weather data provided by the National Weather Bureau. Environmental data was monitored for Wilton, Maine which can then be used as a correlation for actual plant performance especially in solar input as a function of ambient temperature, wind velocity, etc. at seasonal times of year.

ELECTRICAL/FUEL CONSUMPTION

This plant has been designed electrically and equipment sized for high efficiency, high power factor and low energy consumption. High pressure sodium lighting has been employed, where possible, selective switching and task lighting throughout. Equipment has been arranged for selective running from emergency generator depending on gas production.

All significant electrical usage was monitored and audited by function so the total energy requirements for systems such as solar can be determined.

Digester gas production and propane usage were recorded.

EXHAUST AIR HEAT RECOVERY

An air-to-air heat exchanger is used to recover heat from plant exhausts. The efficiency for varying conditions were determined and the increased fan power pressure drops were recorded.

DOMESTIC HOT WATER SYSTEM (DHW)

The DHW system is designed to recover heat from either the storage tank or the system return water whenever possible. A hydronic BTU computer monitored its output along with the electrical input. System losses and the recovery pump requirements were determined.

PROCESS FLOW

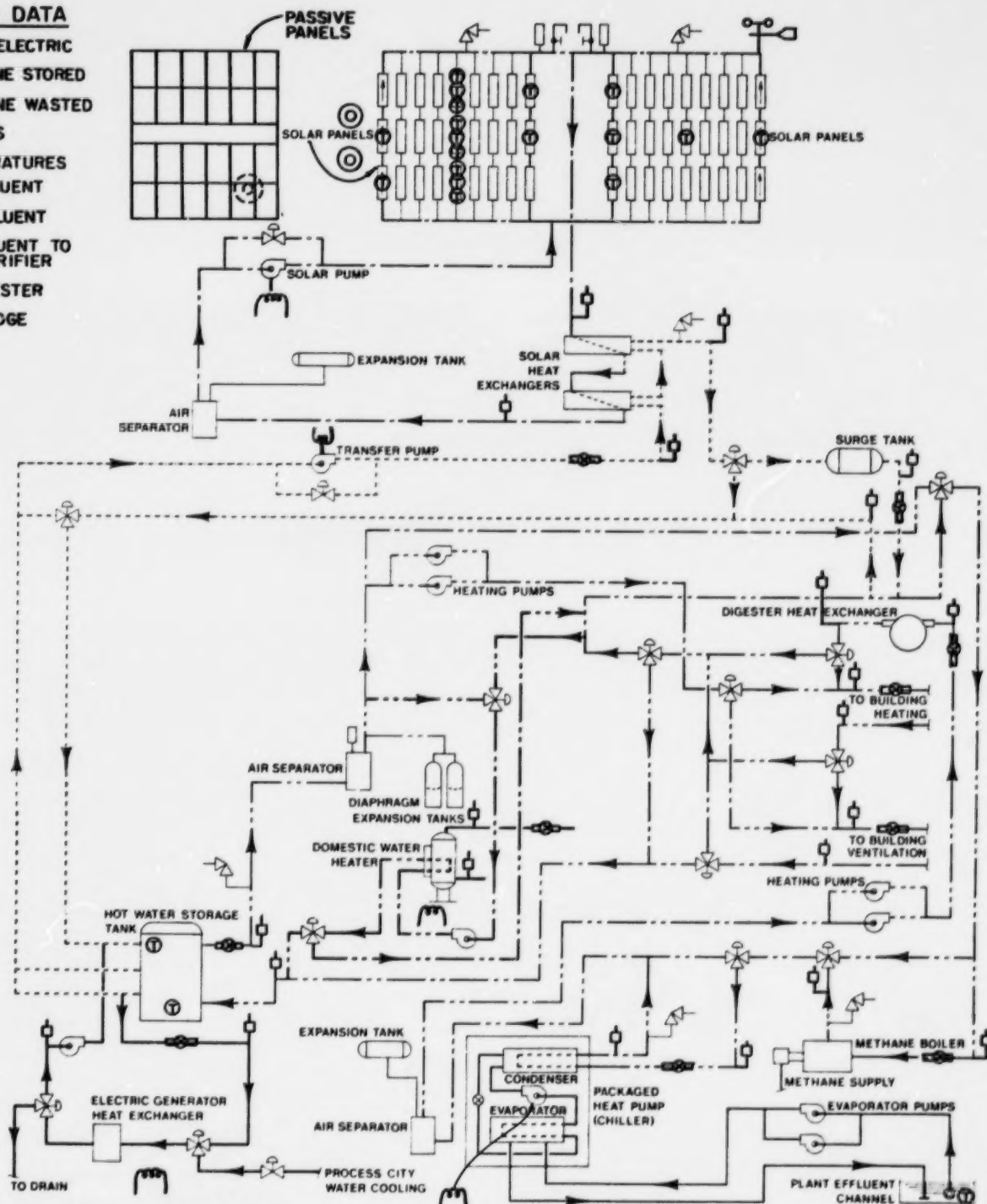
Temperatures are being recorded at various points to determine the heat transfer between the process flow and the plant.

FIGURE 3.1

MONITORING INSTRUMENTATION

OTHER DATA

TOTAL ELECTRIC
METHANE STORED
METHANE WASTED
LP GAS
TEMPERATURES
INFLUENT
EFFLUENT
INFLUENT TO
CLARIFIER
DIGESTER
SLUDGE



HEATING SYSTEM FLOW DIAGRAM

— GENERATOR HEAT RECOVERY SYSTEM
--- ETHYLENE GLYCOL WATER LOOP
... HEAT PUMP EFFLUENT PIPING
-.- SOLAR ENERGY TRANSFER LOOP
-.- DOMESTIC WATER HEATING PIPING
-.- HEATING SYSTEM PIPING
⊗ RELIEF VALVE
⊗ CONTROL VALVE
⊗ AIR VENT
⊗ PUMP

⊗ TURBINE METER
⊗ RTD TEMPERATURE TRANSMITTER
⊗ TEMPERATURE POINT
⊗ SOLAR PYROMETER
⊗ ELECTRIC METER

PROJECTED ENERGY REQUIREMENT AND PRODUCTION

PROJECTED ENERGY REQUIREMENTS

The projected energy requirements for building heating, digester heating, and electrical equipment serve as a basis for evaluating actual performance of the respective systems. Equipment sizes, capacities, and operating schedules is described in greater detail in following sections.

Building Heating

The building heating energy requirement consists of three parts: transmission, infiltration, and ventilation. The calculation procedures to be used are those from References 3, 5 and 6. No allowance for passive solar heat gain or snow cover will be taken, which is consistent with the above referenced calculation procedures.

Transmission and Infiltration

The building transmission and infiltration heat losses are calculated using the building data of Appendix B and an indoor design temperature of 55 degrees F. To determine the monthly energy required, the Modified Degree Day Method⁽²⁾ is used and then distributed on a monthly basis according to the average monthly outdoor air temperatures of Appendix C. The results are recorded in Table 4.1.

Ventilation Air

The building ventilation air heating requirement is calculated using the building data of Appendix B and operating schedules of Appendix D. Unit HV-2 incorporates an air-to-air heat recovery unit which provides 50 percent of the heating ventilation requirement for that unit. The average monthly outdoor air temperature is then used to estimate the monthly energy requirements as recorded in Table 4.1.

Digester Heating

The anaerobic digesters convert the sludge into digester gas containing approximately 65 percent methane, 30 percent carbon dioxide, and the remainder various trace gases. The microorganisms which accomplish this require an ambient temperature of 95 ± 5 degrees F, thus the digesters must be heated to maintain this environment. Also, since the digesters are the continuous flow type, the make-up sludge must also be heated.

The monthly energy requirement to maintain the digestion process is estimated for the transmission losses⁽⁵⁾ and for the make-up sludge heating.⁽⁵⁾

Transmission

The digester transmission heating requirement is calculated using the building data of Appendix B and the outdoor air and ground water temperatures* of Appendix C. At present, one digester is being operated as the primary and the other is used as an unheated secondary digester. The results of heating the primary digester are recorded in Table 4.1.

Make-Up Sludge Heating

The make-up sludge being pumped into the digester must be heated from the temperature of the plant influent** to the temperature of the digester. The monthly energy requirement is calculated using the ground temperatures of Appendix C and the digester system design parameters of Table 5.12. The results are recorded in Table 4.1.

Electrical Usage

The electrical requirements for the facility are based upon motor nameplate data and measured operating data. The operating schedules for each major piece of equipment appears in Appendix D. The actual measured operating amperage was used to estimate the electrical usage where available.

The electrical requirements are calculated separately for Process Equipment, Heating and Ventilating Equipment, and Lighting. The process equipment includes a wide variety of pumps, blowers, and miscellaneous equipment to ensure proper plant operation. The heating and ventilating equipment includes pumps, fans, and heaters for the building heating system, solar system, the heat pump, the emergency generator and the domestic hot water heating. The results are recorded in Table 4.1.

*The ground temperature is taken at the ground water temperature.

**The plant influent temperature is taken at the ground temperature.

PROJECTED ENERGY REQUIREMENTS SUMMARY

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PROJECTED ENERGY PRODUCTION

The energy produced by the various sources, including the active and passive solar, the gas boiler, the heat pump, and the generator heat recovery can be estimated from design performance criteria. These projected energy source contributions will then serve as a basis for evaluating actual performance of the respective systems.

Passive Solar

The passive solar array consists of 896 square foot of panels with an effective collection area of 812 square feet facing 2° west at south at an angle of 60° from the horizontal. The transmissivity is listed as 66% from the manufacturer's literature.

The heating energy supplied by the passive solar system is estimated by using the estimated incident solar insolation of Table 4.3, a cloud cover factor from Appendix F (Albany, New York), a transmissivity of 66%, and an overhand shading factor from Appendix L.

Since the heating provided by the passive array is usable in the Clarifier Room only and cannot be used elsewhere, the net contribution of the passive system will be determined in Table 4.2, below, and transferred to Table 4.6.

TABLE 4.2

NET PASSIVE SOLAR CONTRIBUTION

Month	Design Heat Loss Monthly (MBTU)	Passive Solar Collected (MBTU)	Net Passive Solar Contribution (MBTU)
J	18.7	11.8	11.8
F	17.1	14.8	14.8
M	13.2	17.6	13.2
A	6.6	15.6	6.6
M	0	14.7	0
J	0	14.4	0
J	0	15.4	0
A	0	17.1	0
S	0	17.5	0
O	2.1	17.2	2.1
N	8.0	11.1	8.0
D	12.6	9.5	9.5

ESTIMATED INCIDENT SOLAR ENERGY ON ARRAY - BTU/HR-FT.²26

ESTIMATED NET ENERGY COLLECTION OF SOLAR ARRAY - 1000 BTU'S / HOUR

ESTIMATED NET ENERGY COLLECTION OF SOLAR ARRAY -- 1000 BTU'S / HOUR													
LOCAL SOLAR TIME	15th DAY OF MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	8	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	9	10.0	42.6	57.2	52.6	46.3	41.5	51.3	64.6	70.8	66.5	36.0	0.
	10	91.0	117.6	127.1	114.5	100.3	94.7	103.5	120.8	134.9	137.5	113.1	82.2
	11	146.7	172.1	179.2	161.0	141.1	132.0	141.4	163.1	182.9	189.7	167.5	138.2
	12	171.2	197.0	203.5	183.0	160.4	149.7	159.3	183.1	205.4	213.8	191.8	162.4
	1	160.4	187.7	195.4	176.0	154.4	144.2	153.7	176.6	197.9	205.1	181.7	151.1
	2	114.3	145.0	155.8	141.2	124.1	116.6	125.6	145.0	161.4	164.4	137.5	103.8
	3	34.0	74.2	91.6	85.2	75.5	72.2	80.4	94.1	102.6	98.0	62.4	20.0
	4	0.	0.	13.3	18.1	9.5	7.7	16.2	29.5	32.1	14.5	0.	0.
												</	

Active Solar

The active solar array consists of 54 double-glazed panels with an effective collection area of 1,286 square feet facing 2° west of south at an angle of 60° from the horizontal.

The specification and installation details are described in greater detail in Appendix M.

The heating energy supplied by the active solar system is estimated by the manufacturer in the Tables 4.3 and 4.4, and a cloud cover factor from Appendix F (Albany, New York). Since the heating provided by the active solar system is useful only when such heating is required, the net active solar contribution is determined in Table 4.5, below, and transferred to Table 4.6.

TABLE 4.5

NET ACTIVE SOLAR CONTRIBUTION

Month	Total Heating Requirement Remaining after Passive Solar Contrib. (MBTU)	Available Active Solar Energy (MBTU)	Net Active Solar Contribution (MBTU)
J	97.72	9.70	9.70
F	85.35	13.84	13.84
M	67.54	16.81	16.81
A	45.96	14.82	14.82
M	27.46	14.35	14.35
J	19.58	14.12	14.12
J	16.71	16.23	16.23
A	16.93	18.48	16.93
S	17.84	18.93	17.84
O	33.65	18.25	18.25
N	52.93	10.41	10.41
D	69.91	7.75	7.75

Emergency Generator

The emergency generator set provides electrical power to the facility during an electrical power outage. The fuel available to the generator is plant methane or propane, depending upon the quantity of methane which has been stored. The generator is cooled with the building heating system water, thereby extracting the otherwise wasted energy of the generator cooling system. During normal operation the generator is exercised once a week for an average of 60 minutes.

For estimation purposes the electrical conversion efficiency of the generator and the heat recovery efficiency will be taken as 25% and 50% respectively. From the electrical usage data presented earlier, the average electrical power required during the exercise period will be taken as 40KW. The monthly contribution to the building heating requirement is summarized in Table 4.6. When no building heating is required, the generator is cooled by city water and the cooling water heating energy is not recovered.

Gas Boiler

The gas boiler uses the digester gas produced by the digestion process to provide additional heating energy when that supplied by the solar systems is less than that required by the building. The gas used is that which has been collected, compressed, and stored in the high pressure storage tanks. The high pressure gas is stored in two 1,000 gallon tanks at a maximum pressure of 200 psia.

The quantity of digester gas which should be produced was estimated at 1,650 scf/day with a heating value of 600 Btu/scf. The usable storage capacity is then 4,000 scf @ 200 psia, with a total heating value of 2.4 MBTU. This is a storage capacity of 3 days gas production.

To estimate the monthly heating contribution of the gas boiler, a combustion efficiency of 80% is used. Also, during the months when the boiler does not require all the methane which is produced, the remainder will be assumed to be stored in the high pressure tanks up to a usable maximum of 4,000 scf and used at a later date. The monthly contribution is summarized in Table 4.6.

Heat Pump

The heat pump provides additional heating energy when that supplied by the solar systems is less than that required by the building and digester gas is not available for the boiler. Specifications for the heat pump are listed in Appendix I.

For estimation purposes, the difference between the total heating requirement of Table 4.6 and all other heating sources is taken as that to be supplied by the heat pump.

TABLE 4.6

PROJECTED ENERGY SOURCES (MBTU)

Month	Passive Solar Contribution	Active Solar Contribution	Emergency Generator Contribution	Methane Boiler Contribution	Heat Pump Contribution	Total Heating Contribution
January	11.8	9.70	1.1	14.45	69.37	106.42
February	14.8	13.84	1.1	13.39	57.02	100.15
March	13.2	16.81	1.1	14.45	35.18	80.74
April	6.6	14.82	1.1	13.92	16.12	52.56
May	0	14.35	1.1	12.01	0	27.46
June	0	14.12	1.1	4.36	0	19.58
July	0	16.23	0.48	0	0	16.71
August	0	16.93	0	0	0	16.93
September	0	17.84	0	0	0	17.84
October	2.1	18.25	1.1	14.30	0	35.75
November	8.0	10.41	1.1	15.84	25.58	60.93
December	9.5	7.75	1.1	14.45	46.61	79.41
ANNUAL	66.0	171.05	10.38	117.17	249.88	614.48

Summary

From Table 4.6 the monthly and annual percent contribution of each heating source can be determined. These percentages are listed in Table 4.7 below.

TABLE 4.7

PERCENT ENERGY SOURCE CONTRIBUTION

Month	Passive Solar	Active Solar	Emergency Generator	Methane Boiler	Heat Pump
J	11	9	1	14	65
F	15	14	1	13	57
M	16	21	2	18	43
A	13	28	2	27	31
M	0	52	4	44	0
J	0	72	6	22	0
J	0	97	3	0	0
A	0	100	0	0	0
S	0	100	0	0	0
O	6	51	3	40	0
N	13	17	2	26	42
D	12	10	1	18	59
ANNUAL	11	28	2	19	40

ACTUAL ENERGY REQUIREMENT AND PRODUCTION

The data for the energy monitoring system was generally collected once a day at 7:00 am. However, on occasion, the recording times varied and at times data was lost due to power failure at the facility. See Chapter 7 for further details. Also, in the data collection routine, there is an element of possible human error and/or imprecision. For each month, generally only a few days' data have been lost to such problems. The data presented in Table 5.3 represents the energy usage for the entire month. The days with no data are included at the average of those days of the month with valid data.

All data for all users were monitored at the point of use, thus distribution losses will not be included in the energy requirements, but will be reflected in the difference between the energy required and energy produced.

ACTUAL ENERGY REQUIREMENTS

The results from the monitoring system data will be presented for the building heating, digester heating and electrical systems. These results will then be compared with the projections of Chapter 4.

The energy users include the building heating, digester, domestic hot water, HV-1, HV-2, and all electrical equipment. The individual usage of each and the total of all users are listed in Table 5.3.

Digester

The heating requirement of the digestion process is a significant portion of the total requirement of the facility. The monitoring data have been selected and evaluated giving the figures in Table 5.1 and Table 5.3. These monthly figures represent both transmission losses of the digester and make-up sludge heating. Also listed below are the monthly projected heating requirements for the digestion process heating from Table 4.1 as a comparison.

The actual digester heating varies considerably from the projections from June to September. This is due basically to operational and instrumentation problems encountered during startup and testing of the various systems. (See Chapter 7) From September on, most of these problems were corrected and the actual performance stabilized and closely matched the projected performance. Once the process is optimized, the actual requirements should be significantly lower than projected.

TABLE 5.1

DIGESTER HEATING SUMMARY

Month	Digester Heating		Total Heating*		Percentage of Digester	
	Requirements (MBTU)		Requirements (MBTU)		Heat to Total	
	Projected		Projected		Actual	
	Table 4.1	Actual	Table 4.1	Produced	Projected	Actual
J	31.69	31.780	106.42	97.263	30	33
F	29.47	21.720	100.15	89.053	29	24
M	30.25	31.868	80.74	88.040	37	36
A	26.31	--	52.56	--	50	--
M	23.42	--	27.46	--	85	--
J	19.58	9.264	19.58	17.190	100	54
J	16.71	7.206	16.71	10.404	100	69
A	16.93	10.957	16.93	16.607	100	66
S	17.84	18.109	17.84	28.122	100	64
O	21.62	21.169	35.75	45.072	60	47
N	24.57	20.071	60.93	45.569	40	44
D	28.92	29.725	79.41	83.777	36	35
Annual	287.31	251.60**	614.48	601.12**	47	51*

*Total Heating includes the digester and building loads

**Using projected figures for April and May

Domestic Hot Water

The monitoring on the domestic hot water system indicates that usage has been steadily increasing during the year. This is due to increased laboratory work required as the plant becomes fully operational, plus an additional person has been hired which increases the number of full-time employees from two to three. Additionally, the temperature of the water has been raised on occasion, thereby, while not increasing usage, the meter has reflected the higher energy content. The summary of the domestic hot water usage is given in Table 5.3.

Building Heating

The building heating loop includes all unit heaters, cabinet unit heaters, etc., heating the building generally. Due to temperature transmitter setpoint drift (see Chapter 7), this monitoring point was not operational until March. Thus the data presented in Table 5.3 is the estimated energy usage based on the data recorded from March 1 to March 26 and weighted with the monthly OA temperature actually experienced and an indoor temperature of 55 degrees Fahrenheit (the value used was 15,360 Btu per day °F).

Heating and Ventilating Unit HV-1

A persistent automatic low temperature cutout problem was experienced on HV-1 during the winter which was attributable to temperature transmitter setpoint drift (see Chapter 7). The situation has now been corrected. The monitoring data, however, is still valid, but does not represent what the total heating requirement at this unit would have been. But for purposes here, the data are valid as far as the energy actually required during the year. Table 5.3 summarizes the data on HV-1.

Heating and Ventilating Unit HV-2

Some of the monitoring equipment on HV-2 has been found to be improperly applied and is in the process of being replaced. No data can be considered valid for this unit until such corrections are made. Thus, for purposes here, estimates will be made on the heating energy which would have been required by this unit.

This unit incorporated an air-to-air heat recovery unit which has been tested several times to determine its performance. No continuous monitoring equipment was applied to this unit.

The heating required for HV-2 to heat the outside air to 55 degrees Fahrenheit is estimated using the average monthly outside air temperatures of Appendix C. Estimates for the heating and electrical requirements will be made both with and without the heat exchanger. These estimates can then be used to evaluate the annual performance. The thermal efficiency of the heat exchanger is taken as 67% from Appendix J. The increase in pressure requirements on the two fan motors (HV-2 and EF-4) is also included in Appendix J and the increase in the electrical energy requirements is then estimated from the fan manufacturer's literature.

The results of all these calculations are summarized in Table 5.2.

ACTUAL ENERGY PRODUCTION

The results of the monitoring system data will be presented for the active and passive solar, heat pump, methane boiler, generator, and domestic hot water (electrical) systems. These results will then be compared with the projections of Chapter 4. Each system will now be analyzed and the results listed in Table 5.3 as the total net system contribution as a source of energy.

TABLE 5.2 AIR-TO-AIR HEAT EXCHANGER SUMMARY

MONTH	OPERATING HRS.	HV-2/EF-4 CFM of OA	OAT (°F)	HEATING ENERGY REQUIREMENTS (MBTU)		HV-2 ELECTRICAL ENERGY REQUIREMENTS (1)				EF-4 ELECTRICAL ENERGY REQUIREMENTS (1)			
				WITHOUT Z-DUCT	WITH Z-DUCT (SEE APPENDIX J)	WITHOUT Z-DUCT		WITH Z-DUCT		WITHOUT Z-DUCT		WITH Z-DUCT	
						TSP	BHP	KWH	TSP	BHP	KWH	TSP	BHP
JAN.	177	2610	20	17.54	5.79	1.23	1.03	170	2.10	1.44	238	1.0	1.19
FEB.	157		18	16.45	5.43			151			211		174
MAR.	177		30	12.53	4.13			170			238		196
APR.	171		(41) ²	(6.78) ²	(2.24) ²			164			230		190
MAY	177		(52) ²	(1.50) ²	(0.50) ²			170			238		196
JUN.	171		62	0	0			164			230		190
JUL.	177		71	0	0			170			238		196
AUG.	177		62	0	0			170			238		196
SEPT.	171		54	0.48	0.16			164			230		190
OCT.	177		46	4.51	1.49			170			238		196
NOV.	171		40	7.26	2.40			164			230		190
DEC.	177		25	15.04	4.96			170			238		196
ANNUAL	2080			82.09	27.00			1997			2797		2306
ENERGY SAVINGS					55.09								
ENERGY INPUT											800		994

(1) FROM MANUFACTURER'S LITERATURE

(2) ANTICIPATED ACTUAL AVERAGE MONTHLY TEMPERATURES. FROM JUNE 79 TO MAR 80, THE ORIGINAL PROJECTED OA TEMPERATURES ARE 1° WARMER, ON THE 10 MONTH AVERAGE, THAN THE ACTUAL MEASURED TEMPERATURE.

TABLE 5.3 ENERGY CONTRIBUTION SUMMARY - USERS AND PRODUCERS

USERS	JUNE	JULY	AUGUST	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MARCH
DIGESTER	9.264	7.206	10.957	18.109	21.169	20.071	29.725	31.780	21.720	31.868
DHW	0.506	0.104	0.096	0.081	0.584	0.562	1.741	2.279	4.759	1.983
BLDG. HTG. (5)	0	0	0	0	0.48	6.77	14.10	16.67	17.19	12.126
HV-1	0.021	0.031	0.028	0.056	0.503	1.470	8.273 4.823	11.036 6.733	6.722 4.793	6.214 3.083
HV-2	0.199 ¹	0.023 ¹	0	0.250 ²	2.34 ²	3.77 ²	7.78 ²	9.08 ²	8.98 ²	6.487 ²
TOTAL	9.990	7.364	11.081	18.496	25.076	32.643	66.439	77.575	64.161	61.758
PRODUCERS										
ACTIVE SOLAR	9.776	8.466	12.233	24.473	10.106	7.795	10.749	7.064	12.562	13.332
PASSIVE SOLAR(4)	0	0	0	0	2.78	6.46	9.55	10.68	12.71	10.49
GENERATOR	0.310	0.992	0.422	0.433	0.327	0.519	1.130	1.009	1.263	1.578
BOILER	5.459	0.007	0.019	0	0.043	0	11.424	7.859	0.007	0.016
HEAT PUMP	0.530	0.005	3.586	2.897	30.892	30.000	50.022	69.707	60.808	61.348
DHW (ELEC)	1.115	0.934	0.347	0.355	0.924	0.795	0.902	0.944	1.703	1.276
TOTAL	17.190	10.404	16.607	28.158	45.072	45.569	83.777	97.263	89.053	88.040

(1) BTU METER (2) ESTIMATED VALUE USED FROM VENTILATION REQUIREMENTS.

(3) ADDITIONAL REQUIRED FROM PASSIVE SOLAR SECTION

(4) FROM PASSIVE SECTION (5) ESTIMATED VALUE FROM MARCH DATA.
TANK TEMP. SETTING WRONG (DRIFTED).

Passive Solar

The passive solar panels located in the Clarifier Area are constructed of 4 layers of fiberglass sheeting with aluminum bracing. According to the manufacturer, the U factor is $0.29 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$ and the transmissivity is 66%. The total area is 896 square feet with an effective light transmissive area (aperture) of 812 square feet. The panels are facing 2 degrees west of south at an angle of 60 degrees to the horizontal. A building overhang provides partial shading in the summer and allows for full exposure in the winter, thereby aiding in summer cooling and winter heating. To further aid in winter heating, the building is designed such that light reflected from the snow cover is directed to the passive array.

The panels were evaluated according to solar transmissivity, energy effectiveness, overall collector performance, durability, and practicality.

Solar Transmissivity

The transmissivity of the panels is being monitored by using pyronometers on either side of the panels and measuring both the incident and the transmitted solar radiation. The peak hourly and average daily transmissivity is recorded in Table 5.4.

The peak noon time transmissivity ranges from 35% in July to 57% in January. Part of this reduction from the 66% estimated transmissivity is due to the overhang. The remainder of the reduction is obviously due to other factors such as dust on the panels and surface reflection due to the sun-panel angle.

Energy Effectiveness

The energy effectiveness of the passive array in the Clarifier Room is estimated using building and weather design data and then comparing the estimate with actual data collected by the energy monitoring system. The estimated energy usage is based on the building data of Appendix B, the actual weather data of Appendix C, and a Clarifier Room temperature of 55°F . The actual energy usage is based on the same building data and weather data, but also on the actual Clarifier Room temperature and the solar radiation transmitted through the panels as determined in the previous section. The total passive solar energy contribution is then determined, and the additional heating required is determined.

The energy usage is then estimated for the Clarifier Room were the passive array replaced with a block wall. All the energy then required would be supplied by the building heating source. The difference between the additional heating energy required with the passive panels and the heating energy required without them is a measure of the energy effectiveness of the passive panels.

Table 5.5 summarizes this data.

Overall Evaluation

The passive array is also being studied to determine:

1. Lighting energy contribution
2. Utilization of the material as a wall surface
3. Durability

1. Lighting Energy Contribution

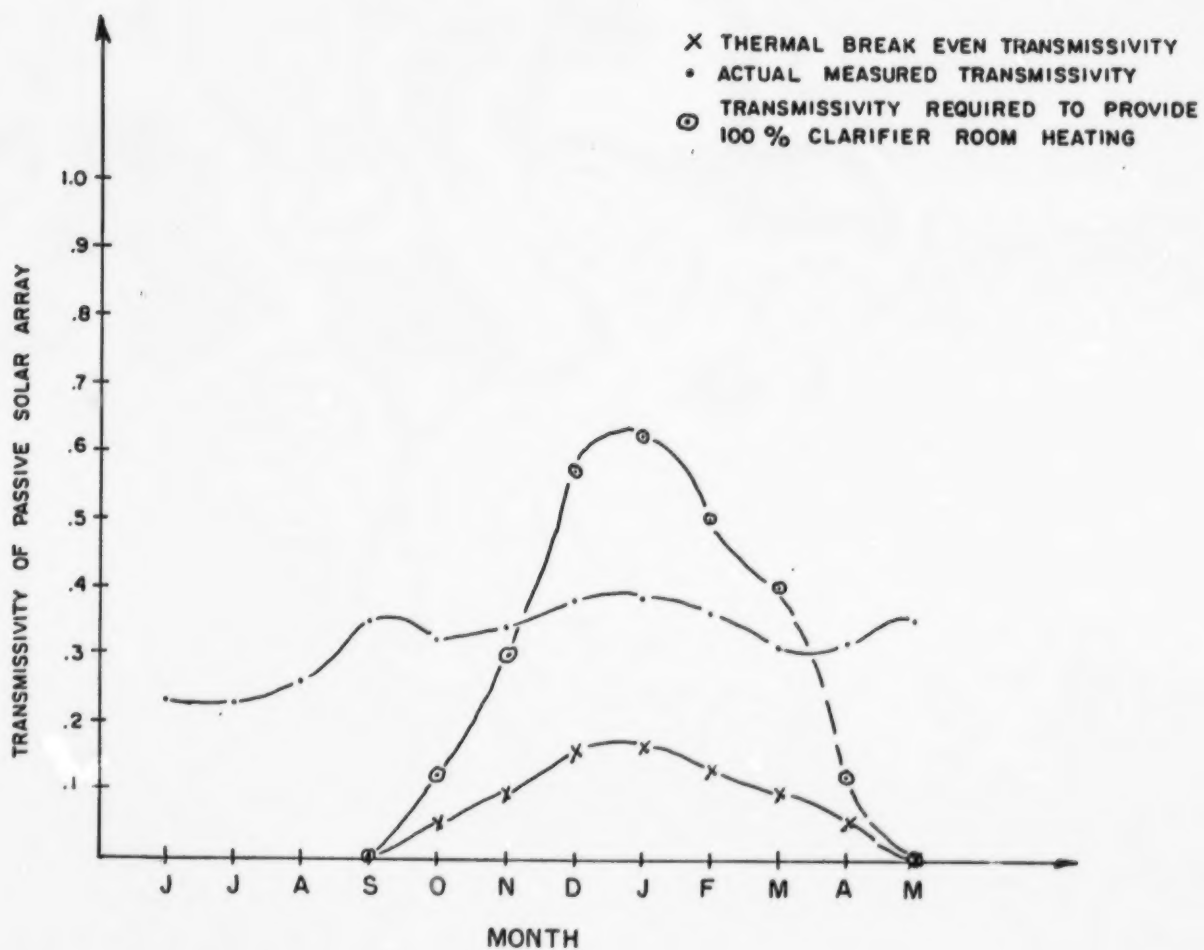
The lighting levels during the day light hours are generally sufficient to operate the facility.

2. Utilization of the Material as Wall Surface

The material as a wall surface has now been installed for a period of about 3 years. Minor intermittent condensation has been observed within the layers of transparent panels. This is considered normal for such units. The moisture does not appear to have a cumulative effect. Leaks have occurred in the weep holes and the perimeter framing. Both conditions have been attributed to the sixty degree slope of the glazed surface. Removal and reinstallation have corrected the leaking. A slight yellow discoloring of south surface areas has been observed.

3. Durability

The longevity, stability and consistent performance of the materials in the wall appear to be unchanged since installation with the exception of a slight yellow discoloring of the exterior surface. It appears to be a reaction of the film coating.



PASSIVE PANEL TRANSMISSIVITY
FIGURE 5.1

TABLE 5.4
PASSIVE COLLECTOR TRANSMISSIVITY

Month	ANTICIPATED *			MEASURED **		
	INCIDENT INSOLATION		TRANSMISSIVITY***	INCIDENT INSOLATION		TRANSMISSIVITY
	Peak Noon (Btu/ft ² -hr)	Avg. Mo. (Btu/day-ft ²)	Peak Noon (Btu/ft ² -hr)	Ave. Mo. (Btu/day-ft ²)	Peak Noon (Btu/ft ² -hr)	Avg. Mo. (Btu/day-ft ²)
J	284.3	710.0	187.6	468.6	337	1119.0
F	298.9	989.9	197.2	653.3	322.5	1481.9
M	296.3	1059.3	195.6	699.2	353.3	1332.6
A	269.3	973.0	177.8	642.2	--	--
M	226.7	883.2	149.6	582.9	--	--
J	210.6	893.1	139.0	589.4	218	1294.3
J	215.3	927.9	142.2	612.4	231	1334.6
A	247.7	1031.9	163.5	681.1	280	1252.7
S	277.1	1088.0	182.9	718.1	306	1692.5
O	290.7	1035.6	191.9	683.5	314	919.8
N	289.3	700.4	190.9	462.3	315	870.0
D	272.7	574.6	180.0	379.2	328	1010.0
					177	379.3

* Solar Data from Table 4.3, Appendix L and Appendix F
 ** See Appendix L for overhang correction factors
 *** From Manufacturer's Data (66%)

Table 5.5

PASSIVE SOLAR ENERGY PERFORMANCE

Month	Design Heat Loss Clarifier Room with Passive Array (MBTU)	Net			Additional Heating Required (MBTU)	Design Heat Loss Clarifier Room without Passive Array (MBTU)
		Actual Passive Energy Collected (MBTU)	Passive Solar Energy Contribution (MBTU)			
January	-17.41	10.68	10.68	6.73	-12.63	
February	-17.50	12.71	12.71	4.79	-12.78	
March	-13.57	10.49	10.49	3.08	-10.16	
April	-	-	-	-	-	
May	-	-	-	-	-	
June	0	7.39	0	0	0	
July	0	7.62	0	0	0	
August	0	8.09	0	0	0	
September	0	14.59	0	0	0	
October	-2.78	7.37	2.78	0	-1.55	
November	-6.46	7.10	6.46	0	-4.48	
December	-14.37	9.55	9.55	4.82	-10.27	
TOTAL	-72.1	95.6	52.7	19.4	-51.9	

1. Clarifier room heat loss using an inside temperature of 55° Fahrenheit and actual OAT and GWT.

2. Clarifier room heat loss substituting an insulated masonry wall for the passive array.

Active Solar

The active solar energy system is the primary source of heating energy for the building. When heating is required and the solar system is operating, the other sources provide supplemental heating as required. When heating is not required and the solar system is operating, the storage tank is heated for later use. The anticipated operating conditions and physical arrangement are described in Chapter 4.

The available insolation is measured as a reference on which to evaluate actual collector and system performance. The percentage of insolation attributable to reflection is also determined by use of a shielded pyronometer which eliminates the reflected component.

Insolation

The available insolation is the total solar radiation incident on the collectors including reflected radiation. Table 5.6 below summarizes the measured insolation for peak noon and daily average and how the same values used in the design calculations compare.

TABLE 5.6

INSOLATION

Month	Peak Noon (BTU/FT ² -HR)			Average Daily (BTU/FT ² -DAY)		
	Estimated (Table 4.3)	Measured	% of Est	Estimated (Note 1)	Measured	% of Est
J	284	333	117	710	1,138	160
F	308	328	106	1,020	1,507	148
M	309	359	116	1,103	1,313	119
A	--	--	--	--	--	--
M	--	--	--	--	--	--
J	245	253	103	1,038	1,457	140
J	248	262	106	1,067	1,509	141
A	266	297	112	1,110	1,308	118
S	289	311	108	1,133	1,737	153
O	300	319	106	1,068	934	87
N	289	311	108	690	856	124
D	273	324	119	575	1,040	181

NOTE 1: From Table 4.3 and Appendix F (Albany, New York)

The increase in incident solar radiation due to reflection from the ground was determined using two pyronometers. One pyronometer measured the total incident insolation and one measured the total incident insolation minus ground reflectance. To accomplish this a shield was placed on one pyronometer which shades it from all incoming radiation below the horizon.

The design of the building and location of both the active and passive solar panels is such that a maximum of reflected radiation will be reflected to the arrays, thereby increasing the amount of solar radiation available for collection or transmittance.

During the winter, snow cover should increase the reflected radiation, but this year the ground was seldom covered by any appreciable amount of snow. It was also found that during the spring and summer rainshowers, the shielded pyronometer sometimes read higher than the unshielded due to reflections by the wet shield. This is not considered important because the reflected radiation we are most concerned with is that reflected during the winter heating season.

Due to the minimal snow cover experienced, it is difficult to accurately assess any increase in reflected energy due to the landscaping. On the contrary, there appeared to be no significant increase.

Table 5.7 summarizes the average monthly incident insolation for both the shielded and unshielded pyronometers and the percent difference between the two.

Collector Efficiency

The instantaneous collector efficiency was determined using the data which has been collected and compared with the anticipated performance of Figure 5.2. Table 5.8 summarizes the data relevant to the calculation procedure. Figure 5.3 is the collector efficiency versus temperature-insolation parameter graph for the recorded data.

All calculations use the effective collector area and total measured insolation data. Generally, a minimum of one day per month was selected where the sky was relatively clear, thereby eliminating cloud cover reductions in performance. The next section of this report addresses the collector efficiency for average daily conditions which include cloud cover, rain, snow, etc. Also, days were selected which would be useful in evaluating the performance of the collectors due to the glycol percentage being used.

From Figure 5.2 it can be seen that there is some scattering of the data points. Generally, the points have been below the minimum performance line for fifty percent glycol solution and on the line for zero and thirty percent glycol. Several explanations are possible to explain this scattering of the data points: transitional glycol flow (turbulent-laminar), glycol percentage (variable fluid properties), wind, air within the fluid loop, conduction losses between the collector and structural supports, convection losses between the absorber plate and the rigid insulation, and reflection.

The transport phenomenon of transition from laminar to turbulent flow occurs, it is generally agreed, from between Reynolds numbers of 2,000 to 4,000.

TABLE 5.7

SHIELDED/UNSHIELDED INSOLATION

Month	Peak Noon (BTU/FT ² -HR)			Average Daily (BTU/FT ² -DAY)		
	Unshielded	Shielded	% Difference ⁽¹⁾	Unshielded	Shielded	% Difference ⁽²⁾
J	333	324	3	1,138	980	14
F	328	324	1	1,507	1,333	12
M	359	337	6	1,313	1,109	16
A	--	--	--	--	--	--
M	--	--	--	--	--	--
J	253	253	0	1,457	1,257	14
J	262	257	2	1,509	1,259	17
A	297	297	0	1,308	1,082	17
S	311	311	0	1,737	1,573	9
O	319	319	0	934	801	14
N	311	311	0	856	741	13
D	324	297	8	1,040	939	10

1. Data is within the limits of the instrumentation accuracy.
2. Data actually includes both reflected and diffuse energy which has been shielded.

TABLE 5.8

COLLECTOR PERFORMANCE DATA										* ESTIMATED		** FROM METER READINGS			
MONTH	DAY	TIME	% GLYCOL BY WEIGHT	GLYCOL TEMP OF		COLLECTOR FLUID FLOW (GAL./HR.-FT ²)	SPECIFIC HEAT (BTU/LBM-F) ¹	DENSITY (LBM/GAL)	VISCOSITY (LBM/SEC FT) ²	TUBE VELOCITY (FT/SEC)	REYNOLDS NUMBER	OA TEMP.	INSULATION (BTU/HR.-FT ²)	EFFICIENCY %	
				IN	OUT									FIGURE 5.8	ACTUAL
JAN	6	12N TO 2PM	30 *	119.9	129.7	1.890 *	0.92	8.579	674 X 10 ⁻⁶	0.613	2432	23.4	266.2	51	55
FEB	10	12N TO 2PM	50 *	118.1	129.8	1.831 *	0.84	8.779	1142 X 10 ⁻⁶	0.594	1423	25.7	306.3	55	53
	20	1PM TO 3PM	50 *	123.8	135.0	1.831 *	0.85	8.762	1075 X 10 ⁻⁶	0.594	1509	47.5	246.7	53	62
MAR	16	12N TO 2PM	50 *	130.5	140.6	1.797	0.86	8.746	1008 X 10 ⁻⁶	0.583	1577	31.7	321.3	56	43
	23	11AM TO 1PM	50 *	121.3	136.8	1.831	0.85	8.762	1075 X 10 ⁻⁶	0.594	1509	48.6	318.7	60	66
JUN	26	12N TO 2PM	50	127.6	134.8	1.890 **	0.85	8.762	1075 X 10 ⁻⁶	0.613	1557	73.2	246.4	59	41
JUL	8	12N TO 2PM	50	113.0	122.9	1.890 *	0.84	8.804	1142 X 10 ⁻⁶	0.613	1473	83.9	231.4	64	60
AUG	9	12N TO 2PM	50	125.2	134.3	1.890 *	0.85	8.762	1210 X 10 ⁻⁶	0.613	1383	69.5	278.8	61	46
	22	1PM TO 3PM	0	123.2	131.9	1.936 **	1.00	8.227	348 X 10 ⁻⁶	0.628	4627	76.1	235.2	60	59
	30	12N TO 2PM	0	110.6	118.0	1.936 *	1.00	8.263	394 X 10 ⁻⁶	0.628	4105	81.0	288.3	65	41
SEPT.	7	12N TO 2PM	0	115.3	126.2	1.936 *	1.00	8.253	367 X 10 ⁻⁶	0.628	4401	70.8	284.8	64	61
	18	12N TO 2PM	0	114.6	126.4	1.936 *	1.00	8.253	367 X 10 ⁻⁶	0.628	4401	74.6	293.4	65	64
OCT	18	12N TO 2PM	30 *	120.8	132.0	1.890 **	0.92	8.579	674 X 10 ⁻⁶	0.613	2432	53.3	302.3	60	55
NOV	1	11AM TO 1PM	30 *	113.6	124.0	1.890 *	0.92	8.587	741 X 10 ⁻⁶	0.613	2214	55.0	308.6	62	52 **
	15	10AM TO 12N	30 *	114.7	124.2	1.890 *	0.92	8.587	741 X 10 ⁻⁶	0.613	2214	35.3	299.2	58	47
DEC	21	12N TO 2PM	30 *	117.0	125.6	1.890 *	0.92	8.587	741 X 10 ⁻⁶	0.613	2214	17.6	248.9	48	52

FIGURE 5.2

COLLECTOR PERFORMANCE CURVE (PREDICTED)

MODEL 210F

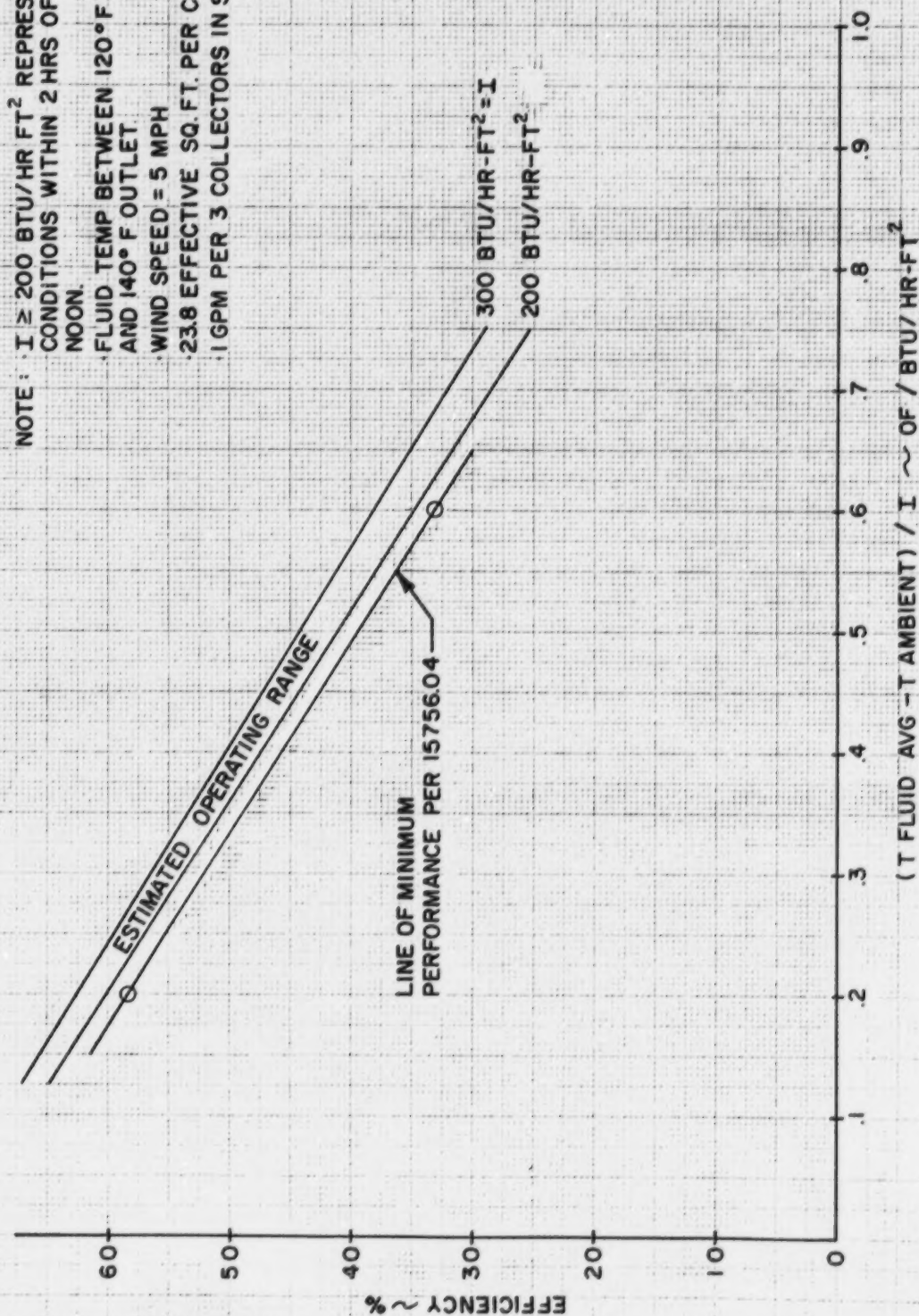
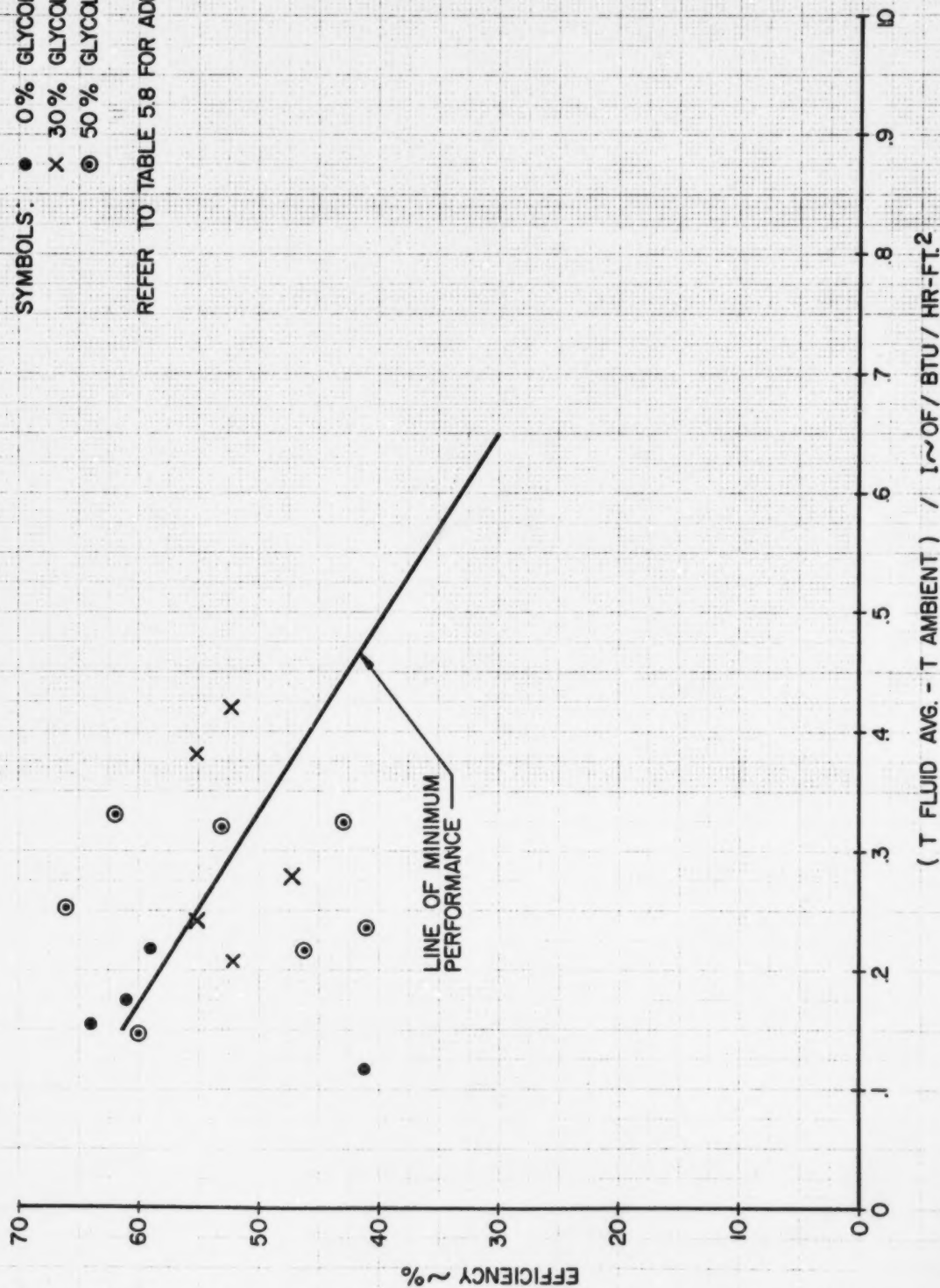


FIGURE 5.3

COLLECTOR PERFORMANCE CURVE (ACTUAL)

SYMBOLS: ● 0% GLYCOL SOLUTION
 X 30% GLYCOL SOLUTION
 ⊙ 50% GLYCOL SOLUTION

REFER TO TABLE 5.8 FOR ADDITIONAL DATA



From Table 5.8, the Reynolds numbers are generally within the transitional phase of fluid flow. When in this range, the flow can be either turbulent or laminar with the associated variation in heat transfer properties.

The percentage of glycol in the collector fluid has been varied in an attempt to determine the affect on collector performance. No consistent, reliable trends were discovered. This is generally due to lack of valid monitored data points and the significant scattering of the points.

The effect of wind speed and direction on collector performance is inconclusive due to limited data (see Chapter 7). Additional monitoring will be required to determine the actual effects of these two parameters.

The effects of reflected solar energy are also inconclusive due to lack of snow cover this last winter. From the section on the reflected solar energy monitored the change in the reflection rate between summer and winter is not significant, thus additional and more precise measurements are required.

Active Solar System Efficiency

The active solar system consists of collectors, pumps, heat exchangers, piping, storage tank, etc. Each component represents a potential for energy loss. The collectors have been analyzed in the previous section. Here, the overall system performance will be evaluated and compared with the estimated performance of Chapter 4.

Table 5.9 illustrates the average daily system performance, the actual sky clearness factor and both the actual and estimated total collected energy.

The only months during which the actual total collected energy equalled or exceeded the estimated total was during September and December.

As indicated, the percent collected averages 23 percent for the ten month period. This long-term efficiency is lower than that estimated by currently accepted calculation procedures. It is not however, inconsistent with other installations which have to be monitored over extended periods (see references 8 and 9). Our findings closely parallel those described in reference 8 from which the following excerpt is taken.

"The percent of sunshine tables are in themselves accurate as a statement of the mean expected percent sunshine for the specific localities shown. The application of percent of sunshine to the heat harvest table for prediction of available solar insolation may, however, lead to an overly optimistic evaluation. Reasons for this consideration follow.

The percent of sunshine tables are developed by use of an instrument that detects full sunshine at any time there is no cloud interference. Thus, on a partly cloudy day, the sun may shine intermittently 25% of the time - and be recorded as such. The problem relative to solar insolation collection is that the intermittent bursts of sunshine may not be of sufficient sustained intensity as to bring collector temperatures up to

TABLE 5.9

ACTIVE SOLAR SYSTEM EFFICIENCY SUMMARY									
MONTH	AVERAGE COLLECTED ENERGY (BTU/DAY-FT ²)	AVERAGE MEASURED INSOLATION (BTU/DAY-FT ²)	PERCENT COLLECTED	AVERAGE * IDEAL INSOLATION (BTU/DAY-FT ²)	SKY CLEARNESS FACTOR	TOTAL ACTUAL COLLECTED ENERGY (MBTU)***	TOTAL ESTIMATED COLLECTED ENERGY (MBTU)**	PUMP P1 (KWH)	PUMP P2 (KWH)
JANUARY	177.3	1138	16	1215	0.94	7.064	9.70	185.08	165.57
FEBRUARY	337.1	1507	22	2001	0.75	12.562	13.84	116.71	114.06
MARCH	334.4	1313	25	2082	0.63	13.332	16.81	74.44	98.23
APRIL	—	—	—	1953	—	—	14.82	—	—
MAY	—	—	—	1781	—	—	14.35	—	—
JUNE	253.6	1457	17	1675	0.87	9.776	14.12	229.00	198.53
JULY	212.5	1509	14	1693	0.89	8.466	16.23	218.40	244.96
AUGUST	307.0	1308	23	1819	0.72	12.233	16.93	172.02	188.08
SEPTEMBER	635.0	1737	37	1954	0.89	24.473	17.84	151.58	138.67
OCTOBER	253.7	934	27	1977	0.47	10.106	18.25	72.29	96.93
NOVEMBER	202.2	856	24	1769	0.48	7.795	10.41	89.82	115.86
DECEMBER	269.8	1040	26	1512	0.69	10.749	7.75	129.54	183.60

* FROM TABLE 4.3

** FROM TABLE 4.6

*** FROM TABLE 5.3

operating level. Thus, absorbed solar heat may not be used - but is simply dissipated by heat transfer back to atmosphere when clouds again interfere.

Another problem relative to solar collection and the percent of sunshine factor has to do with "time appearance" of the sun on a partly cloudy day. If the sun shown 50% of the time during the day and only appeared during the mid-day time range, a high percentage of the potentially available solar insolation could be collected. Conversely, if the sun again shown 50% of the time during the day, but only appeared during the early morning and late afternoon hours while cloud cover occurred during mid-day, only a small amount (if any) of the insolation would be available for collection.

The conventional heat harvest calculation does not take into account the highly variable nature of the percent of sun as this affects available insolation, but rather divides the month into two distinct time periods; a period of absolutely clear, sunny days and another of absolutely cloudy days. For example, if a month has 30 days and a 50% sun factor, the conventional calculation in effect states that for that month, 15 clear sunny days occurred along with 15 absolutely cloudy days. This evaluation is not realistic since it ignores the fact of intermittent cloudiness and leads to overly optimistic evaluations of available insolation."

Emergency Generator

The present use of the emergency generator set is to provide electrical power to the facility during an electrical power outage. The generator is cooled with the building heating system water, providing heating energy to the building. When the storage tank temperature rises above 140 degrees Fahrenheit, city water is used to cool the generator and the recoverable energy is lost.

The Wilton, Maine area has experienced one power outage per month on the average this year and the emergency generator has been used at these times in addition to its regular exercise period each week. Due to the instability of the monitoring instrumentation, during the exercise periods, the electrical energy produced by the generator is not always used in the building. Thus the electrical production meter on the monitoring system has not been active during these periods. The generator can operate on either digester-produced methane or propane. During most of the year, propane has been used (see Chapter 7). Table 5.3 summarizes the monthly generator performance.

Gas Boiler

The methane boiler is used as a source of hot water heating when digester gas is available and more heating energy is required than that being supplied by the solar systems. For various reasons (see Chapter 7), methane has not been available until recently. The heating provided by the boiler

has been supplied by the back-up fuel, propane. Boiler usage, however, has been minimal during the monitoring period.

Table 5.3 summarizes the monthly methane boiler energy production.

Heat Pump

The water-to-water heat pump is used as a source of hot water heating when digester gas is not available and solar production is inadequate. The heat pump recovers heat from the plant effluent prior to discharge from the facility. From the temperature sensors located at various points in the process lines, the temperature of the wastewater as it proceeds through the plant increases. By recovering the energy from the effluent, the effluent temperature is lowered. The heat pump has been the major source of heating during the winter since gas has been unavailable and solar has been inadequate.

The coefficient of performance (COP) of the heat pump varies with the temperature of the effluent, rising with a rise in effluent temperature and dropping as the effluent temperature falls.

Table 5.10 summarizes the monthly heat pump energy production and COP performance.

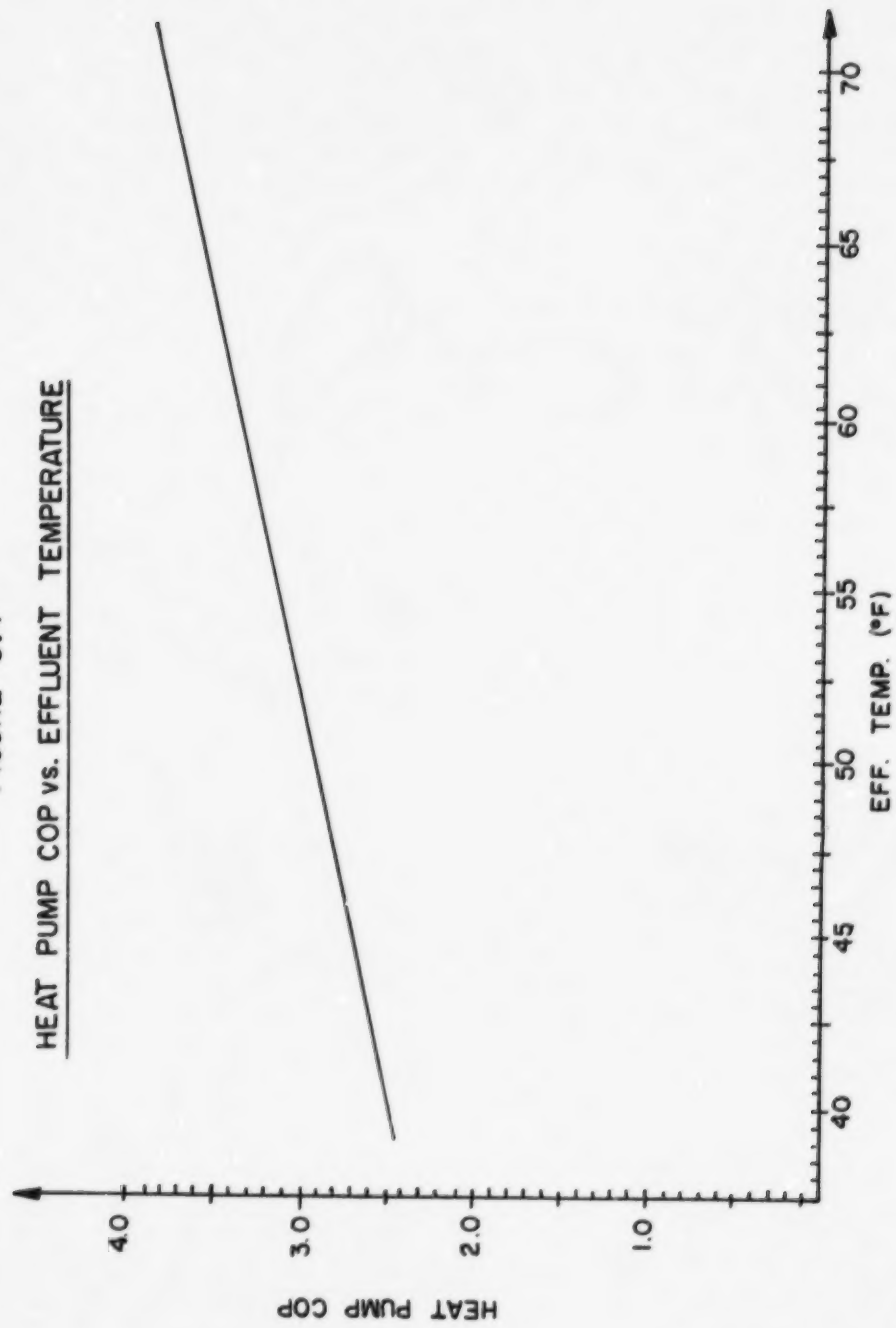
TABLE 5.10

HEAT PUMP SUMMARY

Month	Effluent Temp (°F)	Energy Input (KWH)		Energy Output (MBTU)	COP
		Compressor	Pump		
January	46.0	6807	204	65.21	2.73
February	44.2	6717	202	60.81	2.58
March	43.0	6388	192	59.37	2.64
April*	-	(2112)	(63)	(24.0)	-
May*	-	(2327)	(70)	(26.9)	-
June	60.3	40.5	1	0.488	3.43
July	65.0	0	0	0	-
August	68.0	241.9	7	3.355	3.95
September	66.8	224.9	7	2.607	3.29
October	62.0	2327	70	26.91	3.29
November	56.7	2112	63	24.00	3.23
December	50.3	4363	131	48.41	3.16
Annual		33,660	1010	343.26	2.90

*Estimated

FIGURE 5.4
HEAT PUMP COP vs. EFFLUENT TEMPERATURE



Domestic Hot Water (Electric)

The Domestic Hot Water heating is provided from either the solar storage tank when available, or the tank electric immersion heater. Table 5.11 below summarizes the DHW usage and electrical input required to provide supplemental heating.

TABLE 5.11

DOMESTIC HOT WATER HEATING SUMMARY

Month	DHW Usage (MBTU)	Electrical Input		% Supplied by Electrical
		KWH	Equiv MBTU	
J	2.279	276.5	0.944	41
F	4.759	499.0	1.703	36
M	1.983	374.0	1.276	64
A	---	---	---	---
M	---	---	---	---
J	0.506	326.8	1.115	220
J	0.104	273.7	0.934	898
A	0.096	101.8	0.347	361
S	0.081	104.0	0.355	438
O	0.584	270.6	0.924	158
N	0.562	232.9	0.795	141
D	1.741	264.2	0.902	52

As illustrated above, during the summer and autumn, various problems were experienced with the instrumentation and controls system (See Chapter 7). Also, during the year, the temperature has been changed for various reasons, but since late summer has been set at 110° generally.

Digester Gas Generation

Wilton employs high rate, two-stage mesophilic anaerobic digestion to stabilize and reduce the quantity of sludge. Gas containing approximately 65 percent methane, 30 percent CO_2 , plus trace amounts of other gases is produced as a byproduct of anaerobic digestion. This gas, being compressible, stable and combustible ($22,400 \text{ KJ/m}^3$ (600 BTU/ft^3)) represents a potentially valuable energy resource. At Wilton, the digester gas is collected and stored to be burned in the plant's boiler to supplement solar energy for space and process heating and to fuel the plant's emergency electric generator to meet some of the electric power requirements. A detailed description of the operation of Wilton's digester and digester gas systems has been excerpted from the treatment plant operation and maintenance manual and can be found in Appendix K. Basic design parameters are shown in Table 5.12.

TABLE 5.12

ANAEROBIC SLUDGE DIGESTION SYSTEM CHARACTERISTICS
WILTON, MAINE

<u>Parameter</u>	<u>Design (1996)</u>		<u>Projected, Based On Present (March 1980)</u>	
Plant Influent Flow, m ³ /d (gal/d)	1700	(450,000)	450	(120,000)
Sludge Production				
Quantity, m ³ /d (ft ³ /d)	9.6	(340)*	9.3	(330)**
Total Suspended Solids, kg/d (lb/d)	340	(750)	150	(330)
Volatile Suspended				
Solids, kg/d (lb/d)	250	(560)	125	(275)
Digester Sizing (Per Digester)				
Diameter, m(ft)	6.1	(20)		
Sidewater Depth, m(ft)	4.6	(15)		
Usable Volume, m ³ (ft ³)		133 (4,713)		
Detention Time, d	13.9		15.2	
Total Solids Loading,				
kg/m ³ /d (lb/ft ³ /d)	2.6	(0.16)	1.1	(0.07)
Volatile Solids Loading,				
kg/m ³ /d (lb/ft ³ /d)	1.9	(0.12)	0.95	(0.06)
Gas Production, m ³ /kg VSS				
(ft ³ /lb VSS)	0.63	(10)	0.50	(8)***
Gas Production, m ³ /d (ft ³ /d)	160	(5,600)	63	(2,200)***
Percent Methane	65		65	
Gas Heat Value (BTU/d)*****		(3.36MBTU)		(1.32MBTU)
Percent Volatile Solids Reduction***	48		57	

*4% Solids (Design)

**1.6% Solids (Actual)

***Projected

*****Based on 600 BTU/CF

As of March 1980, approximately ninety percent of the expected initial users of the sewage collection and treatment system had been connected. Flows (and subsequent sludge quantities) were approximately 27 percent of design capacity and less than one half those projected as initial year flows. Possible reasons for lower than expected flows are:

1. Inplant programs of the major industrial users to conserve water.
2. Very little infiltration/inflow.
3. Lower per capita wastewater flows than expected.

As is usual in starting up a new sludge digestion facility, particularly one that is significantly underloaded, Wilton's digesters have undergone an extended process of becoming acclimated and reaching steady state conditions. Consequently, very little meaningful operating data are yet available, and the information that is available indicates that the digesters have not yet achieved optimum steady state conditions.

Low first-year flows at the treatment plant have had a significant effect on the operation of the anaerobic digestion system. As can be seen from Table 5.12, the smaller quantity of sludge produced results in projected gas productions of approximately forty percent of the design quantity. Interestingly, sludge production is approximately forty-four percent of design, while plant flows are only twenty-seven percent. Volatile solids production is even closer to design rate, forty-nine percent, because Wilton's sludge is eighty-four percent volatile rather than seventy-five percent as designed. The relatively large amount of sludge being produced confirms a qualitative observation that RBC biomass is much heavier than expected.

In March, sludge pumped to the digester averaged only 1.6 percent solids, compared to four percent design consistency. The dilution of the sludge means that the hydraulic detention time in the primary digester (15.2 days) closely approached design conditions (13.9 days).

Gas production rates for high-rate digesters should be 0.5 to 0.75 m³/kg (8 to 12 ft³/lb) of volatile solids added, indicating, using .5 m³/kg figure, that 63 m³/d (2200 ft³/d) should be produced. Actually, an average of 31 m³/d (1100 ft³/d) were produced in March. Another "rule of thumb" for gas production is 0.75 to 1.12 m³/kg (12 to 18 ft³/lb) of volatile solids destroyed. Based on volatile solids loading and detention time, one would expect volatile solids reduction to be on the order of 57 percent. Based on measurement of the secondary digester separation, it appears that about sixty-seven percent of the volatile solids in the raw sludge is being destroyed. At that rate, one would expect gas production to be in the range of 63 to 94 m³/d (2210 to 3320 ft³/d). Actual production ((31 m³/d (1100 ft³/d)) falls well under this range also.

As yet, it has not been determined why gas production is not higher. Temperature, pH, volatile acids, bicarbonate alkalinity, percent methane in the gas, and volatile solids reduction, all indicators of digester performance, are within the range expected to produce good digestion. The only apparent factor which may be detrimental is solids concentration in the raw sludge (1.6 percent). Even with the diluted sludge, however, the detention time is greater than design.

Gas production, then, is approximately half that expected (31 m³/d vs. 63 m³/d). However, because the methane content is seventy-nine percent rather than sixty-five percent as expected, the heat value is sixty-four percent of the projected value (0.84 MBTU/d vs. 1.32 MBTU/d). If gas production was in the range of 63 m³/d as the data indicate it should be, the heat value of the gas would be 1.67 MBTU/d and the digesters would be energy self-sufficient (COP greater than 1.0, see Table 5.13).

The lower quantity of digester gas being produced changes the relative importance of the role of methane as an energy source in Wilton. At design flows it is expected that digester gas will provide thirty to thirty-five percent of Wilton's heat requirements. Initially it appears that the gas provides ten to fifteen percent. Lower gas production places more emphasis on solar and the heat pump to provide the heat energy needed.

Due to problems which arose with digester underloading and acclimation and gas handling equipment, limited digester gas production and usage information is available for the monitoring period. Gas production stabilized and the storage, monitoring, and usage systems became fully operational during March 1980. The total heating requirement of the process was monitored and represents the heating requirement of the digester even though very little gas was produced and collected. The limited data collected on the gas production will be used to arrive at a figure for gas production efficiency based on a unit of energy produced (gas) versus unit of energy used (including electrical input).

The electrical equipment associated with the methane generation equipment and daily energy usage, based on their operating schedules of Appendix D, is tabulated below. Table 5.13 also includes the average daily heating energy requirement and the energy production/usage ratio for the process.

From Table 5.13 the energy production/usage ratio indicates that we are producing slightly more than one half unit of energy for every unit used. However, if the digesters were producing as much gas as the operating data indicate they should, the ratio, even at low influent flows being experienced, would be greater than one.

Changes in operating procedures can significantly improve this ratio. Modifications to the raw sludge handling system have been made in an attempt to thicken sludge before pumping it to the digesters. To date, the success of this effort has been limited, constrained by the overriding need to maintain a high quality effluent. Construction of a separate sludge thickener to be used to thicken raw sludge to at least five percent would cut the quantity of sludge being pumped to the digester by sixty to seventy percent, with corresponding decreases in heating requirements. This would increase sludge detention time in the primary digester to enable it to be operated close to standard rate, rather than high rate, while current low wastewater flows prevail. The digesters have been operated as if they were high rate (continuous mixing, heating to mid-mesophilic temperatures) and producing design gas quantities (use of high pressure storage system year round). Given the present loadings, if the sludge were thickened, significant savings in operating costs could be realized by cutting back to intermittent mixing and reducing the digester temperature to the lower mesophilic range (80 to 85 degrees Fahrenheit). This would result in

slower digestion and gas production, but the trade-off in lower operating costs would be cost-effective. It may also be advantageous to eliminate high pressure methane storage in the summer when active solar, with occasional boosts for the heat pump, can provide enough energy for digester heating. These changes in operation would be phased back to normal operation as digester loadings approached design conditions.

TABLE 5.13
DIGESTER GAS GENERATION SUMMARY

Electrical Equipment

<u>Name</u>	<u>ACTUAL</u>		<u>DESIGN</u>	
	<u>KWH/d⁽¹⁾</u>	<u>BTU/d⁽²⁾</u>	<u>KWH/d</u>	<u>BTU/d</u>
Sludge Mixer	5.97	20,380	23.88	81,500
Sludge Recirculation Pump	11.94	40,750	31.84	108,670
Sludge Pump	5.30	18,090	15.90	54,270
Sludge Dewatering Pump	0	0	0	0
Digester-Gas Recirculation Comp.	79.57	271,570	79.57	271,570
Digester-Gas HP Comp.	14.92	50,920	75.96	259,240
Total Electrical	117.70	401,710	227.15	775,250

Heating Equipment

Sludge Heat Exchanger ⁽³⁾	<u>1,028,016</u>	<u>2,923,000</u>
Total Equipment Energy Input	1,429,726	3,698,250
Digester-Gas Generated Energy ⁽⁴⁾	836,000	2,475,000

Digester-Gas Generation Efficiency

$$\frac{\text{Generated Energy}}{\text{Equipment Energy Input}} = \text{COP} = \frac{836,000}{1,429,726} = 0.58 \qquad \frac{2,475,000}{3,698,250} = .67$$

NOTES:

1. See Appendix D for nameplate and operating data. Based on twenty percent motor oversizing and PF = 0.90
2. A conversion of 3,413 BTU = 1 KWH is used.
3. Average daily digester heating for March at 2,475 gal/day.
4. A value of 1,100 scf/day at 760 BTU/scf was used as an estimate of production for March, based on meter readings from April 14 to April 24, and gas analyses indicating 79% methane content.
5. Projected to design conditions.

Electrical Usage

The total outside electrical consumption for the building is monitored and presented in Table 5.14. The actual electrical power used during the 10 month monitoring period was 12.5% less than the projections of Chapter 4.

TABLE 5.14
TOTAL ELECTRICAL USAGE (KWH)

Month	Projected Table 4.1	Actual Measured
January	34,940	29,600
February	33,230	29,920
March	30,840	30,200
April	28,720	--
May	26,940	--
June	26,930	22,680
July	26,920	22,120
August	26,920	26,200
September	26,920	21,000
October	26,930	25,840
November	29,750	23,000
December	32,090	27,880

ENERGY AND COST EFFECTIVENESS

The primary purpose of all the measures included in the design of Wilton Treatment Plan was to reduce the dependence on external energy sources; to become as self-sufficient as possible. The net energy savings of each measure should be such that more energy is saved than is consumed. However, these measures should save money, and should do so within a specified period of time (payback period).

Each measure will now be evaluated for its energy and cost effectiveness and for its individual payback period. The energy produced by each measure is a known quantity and the energy required to produce the energy is either known or can be easily determined through the monitoring system data.

The energy dollar value for the energy produced and used will be based on the following rates as of spring of 1979 when the project was started.

Propane \$.46/Gal. @ 91,000 Btu/gallon
 \$6.32/MBTU @ 80% efficiency

Electricity \$0.045/KWH @ 3,414 Btu/KWH

All data for this evaluation is taken from the appropriate sections of Chapter 5.

TABLE 6.1

CONSTRUCTION COST ESTIMATE SUMMARY

	WILTON	WILTON W/ CONVENTIONAL ENERGY	EST. COST DIFFERENCE	SERVICE LIFE (YR)
1 SITE PREP & LANDSCAPING	102,500	102,500	0	
2 SITE PIPING	45,015	45,015	0	
3 BUILDING & CONCRETE	626,775	580,200	46,575	50
4 PROCESS	624,124	624,124	0	
5 ELECTRICAL	110,500	100,400	10,000	20
6 INSTRUMENTATION CONTROL	148,390	81,000	67,390	20
7 PLUMBING	41,927	41,927	0	
8 H & V	96,422	96,422	0	
9 HEAT PUMP	11,400	0	11,400	20
10 METHANE RECIRC. SYSTEM (DIGESTER MIXING)	34,700	34,700	0	
11 GENERATOR HEAT RECOVERY	2,850	0	2,850	20
12 HP METHANE STORAGE	16,114	0	16,114	30
13 PROPANE STORAGE	6,000	2,500	3,500	30
14 LP METHANE STORAGE	6,120	6,120	0	
15 SOLAR	51,025	10,000	41,025	30
16 SPRAY IRRIGATION	15,300	15,300		
17 CONTRACTING OH & P	224,838	224,792		
TOTAL	2,164,000	1,965,000	199,000	

PASSIVE SOLAR

The passive solar panels are located in the Clarifier Room. They consist of 896 square feet (812 sq. ft. effective area) of 4 layers of fiberglass sheeting with aluminum bracing. The "U" factor and transmissivity are listed at 0.29 and 0.66 respectively. The panels face 2° West of South at an angle of 60° from the horizontal.

Table 5.3 and Figures 1.1 and 1.2 illustrate the net passive solar contribution to the heating system. Tables 5.4 and 5.5 and Figure 5.1 summarize the monitoring data collected during the year and the actual performance of the passive array. The economic analysis shall be based on the difference between the total Clarifier Room heating required without the passive array and the additional heating required with the passive array.

	<u>Energy*</u>	<u>Value</u>
Output:	38.48 MBTU	\$243
Input:	<u>0</u>	<u>0</u>
Net Gain:	38.48 MBTU	\$243
Initial Investment:**		\$7,200

Energy Output/Input Ratio: = N/A

$$\text{Simple Payback} = \frac{\$7,200}{\$243} = 30 \text{ Years}$$

* Neglecting decrease in lighting required.

** Passive panel cost of \$14.75 per sq. ft. x 896 sq. ft., less regular insulated brick-block wall at \$8 per sq. ft. x 775 sq. ft. equals \$7,200 difference.

ACTIVE SOLAR

The active solar system provided 23% of the total heating requirement from June to March. The energy produced and pump power required are presented in Table 5.9. The energy and cost effectiveness and the simple payback period will be based on an annual heating contribution using the monitored data plus the estimated data for the months of April and May. The pump power required for April and May will be taken as the average per unit of energy delivered from the monitored period.

	<u>Energy</u>	<u>Value</u>
Output:	145.7 MBTU	\$921
Input:	12.7 MBTU <u>(3,730 KWH)</u>	168
Net Gain	133.0 MBTU	\$753

$$\text{Energy Output/Input Ratio} = \frac{145.7}{12.7} = 11.5$$

$$\text{Value Output/Input Ratio} = \frac{\$921}{\$168} = 5.5$$

$$\text{Simple Payback} = \frac{\$41,025}{\$753} = 54 \text{ Years}$$

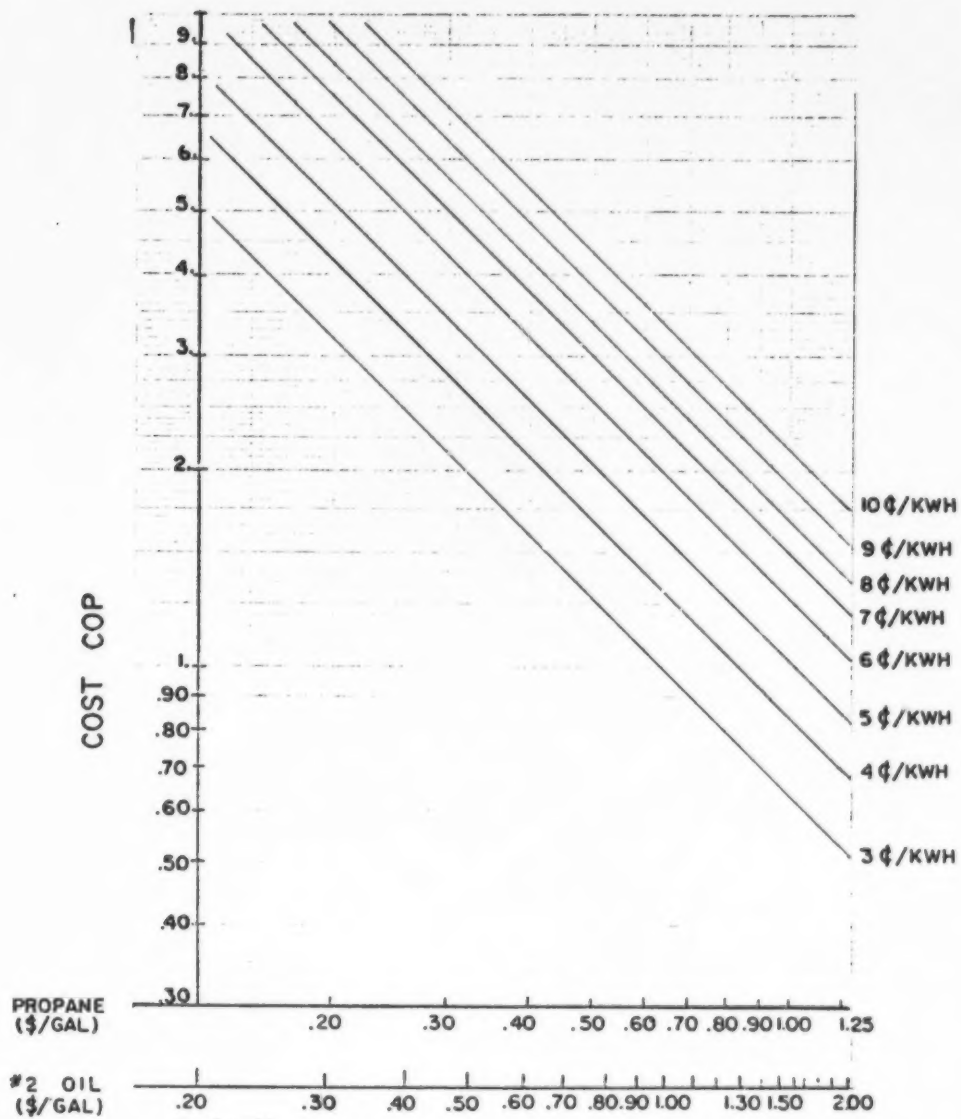
Heat Pump

The effluent-to-water heat pump provided 60% of the total heating requirement from June to March. The energy produced, power required, and other operating conditions are presented below.

To determine whether or not the heat pump system is economically feasible the following two graphs can be used as follows.

Locate the alternate fuel cost on Figure 6.1 and move up to the line which represents the electrical rates (demand and fuel adjustment charges included) and read over to find the minimum Cost COP required by the heat pump. The cost COP represents the minimum COP required such that the electrical cost of the heat pump to deliver a unit of energy equals the value of an equal unit at energy delivered by the alternate fuel.

FIGURE 6.1
HEAT PUMP COST COP PARAMETER



FUEL COSTS

Locate the average temperature of the effluent which should be experienced during the year by the heat pump under normal operating conditions and read off the average heat pump COP from Figure 5.3. This heat pump COP is the COP that represents the units of energy produced by the heat pump for each unit of electrical energy input to it.

If the Cost COP is less than the heat pump COP. then the heat pump is economically feasible. Otherwise, the heat pump would be producing energy but at a cost higher than using the alternate fuel directly.

Once the initial economic feasibility is determined as practical, then further analysis must be done to determine the cost effectiveness of that option.

The present case will now be used as an example:

Alternate Fuel -

Propane at \$6.32/MBTU @ \$.46/gal (91,000 Btu/gal, 80% comb. eff.)

Electricity - 4.5¢/KWH

Cost COP = 2.08

Heat Pump COP = 2.90 (50F avg.)

Therefore - economically feasible

From Table 5.10, the cost effectiveness can be determined.

	<u>Energy</u>	<u>Value</u>
Output:	343.26 MBTU	\$2170
Input:	118.33 MBTU (34.670 KWH)	1560
Net Gain	224.93 MBTU	\$ 610

$$\text{Energy Output/Input Ratio} = \frac{343.26}{118.33} = 2.90$$

$$\text{Value Output/Input Ratio} = \frac{\$2170}{\$1560} = 1.39$$

$$\text{Simple Payback} = \frac{\$11,400}{\$ 610} = 18.7 \text{ years}$$

Emergency Generator Heat Recovery

The generator is cooled with the building heating system water, providing heating energy to the building. The generator can operate on either digester gas or propane. During the monitoring period, digester gas was not available.

The average generator heat recovered was 800,000 Btu/month. The generator operated on the average of one-half hour per week. During the summer it is anticipated that excess digester gas will be used in the generator thus increasing the recovered energy and decreasing the simple payback period accordingly. From Table 5.3 and Appendix D, the cost effectiveness can be determined.

	<u>Energy</u>	<u>Value</u>
Output:	9.60 MBTU	\$ 61
Input	<u>0.085 MBTU</u>	<u>1</u>
Net Gain	9.515 MBTU	\$ 60

$$\text{Energy Output/Input Ratio} = \frac{9.60}{0.085} = 113$$

$$\text{Value Output/Input Ratio} = \frac{\$ 61}{\$ 1} = 61$$

$$\text{Simple Payback} = \frac{\$2850}{\$60} = 48 \text{ years}$$

Air-to-Air Heat Exchanger

The air-to-air heat exchanger is incorporated on the entering air side of Unit HV-2 and the discharge of EF-4 thus heating the incoming air with the warmer exhaust air. From the testing of the heat exchanger, the thermal efficiency of this unit is 67%. The annual energy and cost effectiveness of this unit will be determined utilizing the data of Table 5.2.

	<u>Energy</u>	<u>Value</u>
Output: (HV-2 air heating)	55.09 MBTU	\$348
Input: HV-2	2.73 MBTU (800 KWH)	36
EF-4	3.39 MBTU (994 KWH)	45
Net Gain	48.97 MBTU	\$267

$$\text{Energy Output/Input Ratio} = \frac{55.09}{6.12} = 9.00$$

$$\text{Value Output/Input Ratio} = \frac{\$348}{\$81} = 4.30$$

$$\text{Simple Payback} = \frac{\$3,250}{\$267} = 12.2 \text{ years}$$

Digester Gas Generation

The digesters stabilize and reduce the quantity of sludge which needs to be disposed of while at the same time producing a burnable digester gas composed of approximately 60% methane. For the digesters to operate properly the temperature is maintained at $95^{\circ} \pm 5^{\circ}\text{F}$.

From the limited data available on methane production and actual digester operation parameters, the energy and cost effectiveness determination shall be done for the month of March only. During that month the monitoring data appears to be valid. More data is needed to further ascertain actual conditions and the affect of weather, temperature, pH levels, etc. on digester performance.

	<u>Energy</u>	<u>Value</u>
Output: (Digester Gas Production)	0.84 MBTU/Day*	\$5.31
Input: Heating	1.03 MBTU/Day	6.51
Electrical	0.40 MBTU/Day (117.7 KWH/Day)	5.30
Net Loss =	0.59 MBTU/Day =	\$6.50

$$\text{Energy Output/Input Ratio} = \frac{0.84}{1.43} = 0.58$$

$$\text{Value Output/Input Ratio} = \frac{\$ 6.50}{\$11.81} = 0.55$$

Simple Payback = N/A

*Based on 79 percent methane content of gas, as measured.

*No additional losses are taken here for utilization of the digester gas (combustion losses, etc.)

NOTE: The concentration of sludge pumped into the digester has subsequently been increased. While this will certainly reduce the heat input requirement, insufficient data is available at this time to properly evaluate its effect.

TABLE 6.2
ENERGY AND COST EFFECTIVENESS SUMMARY

Component	Output		Input		Initial Investment (\$)	Energy Output/Input Ratio		Value Output/Input Ratio	Simple Payback Years
	MBTU	(\$)	MBTU	(\$)					
Active Solar	145.7	921	12.7	168	41,025	11.5		5.5	54
Passive Solar	38.48	243	0	0	7,200	32% (1)		N/A	30
Heat Pump	343.26	2,170	118.33	1,560	11,400	2.90		1.4	18.7 (2)
Generator Heat Recovery	9.60	61	0.085	1	2,850	113		61	48
Air-to-Air Heat Recovery	55.09	348	6.12	81	3,250	9.0		4.3	12.2
Digester Gas (3) Production	0.84	5.31	1.43	11.81	N/A	0.58		0.55	N/A

(1) Actual average monthly solar radiation transmitted through panels from June 1, 1979 to April 1, 1980 (See Chapter 5)

(2) Neglecting Maintenance Costs

(3) All values on a per day basis for March 1980.

OPERATIONAL AND DESIGN PROBLEMS

During the months which the plant has operated several operational problems have been encountered. These will be reviewed with the corrective action taken where applicable.

Collector Temperature Stratification

The solar collectors were put into operation in the fall of 1978 with ambient temperatures ranging between 45 and 65°F. During this period, there was no problem in starting the glycol/water circulation pump P-1, which is started in response to the collector plate temperature.

In mid-winter, however, with ambient temperatures between 0 and 30°F, P-1 was not starting even though fluid temperatures at the top of the collector were dangerously high. (The locations for the collector plate thermocouples are shown in Appendix "H".)

The thermocouple originally selected to control P-1 was located at the bottom of the collector array. It was discovered, at these colder outside air temperatures, that there was a temperature gradient between the lowest and highest points on the collector array of as much as 100°F. The array is 18 panels in width and 3 panels high.

The control was switched to the uppermost thermocouple which starts P-1 at the desired set point and protects the system from possible over-heating leading to decomposition of the glycol solution.

Instrumentation Problems

1. A problem was encountered in regard to the solar pump P2 which circulates water through the water side of the glycol-water/water heat exchanger. In brief, the start circuit for the pump was dependent on the glycol temperature leaving the solar collectors. This transmitter sensed an erroneously high temperature whenever the solar storage tank temperature was also high, causing both pump cycling and loss of energy back to the collectors. The problem was corrected by a change of the controlling variable.
2. The pneumatic temperature controllers which provide input to the control logic circuits have been found to have their setpoints drifting considerably. In one case the drift was in excess of 30°F. A contact cement is currently being used to help keep the setpoints from drifting.

3. Due to manufacturing difficulties and delivery schedules encountered, the original flow turbines were replaced by different units. This necessitated some transmitter recalibrations, etc. One of the installed turbine meters is now found to not be producing linear outputs in the range in which it is operating (HV-2). With the best delivery schedule, it was not time enough to receive and install the new unit and generate data for this heating season.
4. The weather station developed a leak in the weatherproofed sensing elements which then gave incorrect readings for wind speed and wind direction. This has been repaired and the weather station has been operating satisfactorily since mid-January.
5. The sludge pump timing mechanism required revisions such that the proper sequence would be followed. The most recent revision was made in mid April which significantly reduced the amount of sludge pumped into the digester. These rates will continue to be adjusted to optimize digester performance. Once the operation has been optimized, as accurate evaluation of the digester gas system can be made.
6. The underground digester gas lines to and from the high pressure storage tanks developed leaks and were repaired. As gas began being provided and these lines used, moisture got into the lines and froze rendering the high pressure storage tanks unusable. Since the gas lines to the equipment using gas were these same lines, the gas which was generated was lost out the vents. The lines were reopened in mid-March and have been operational since. It is believed that during the summer, due to the usage and temperatures the tanks will be experiencing, the moisture will be cleared out.

DESIGN PROBLEMS

Several areas have thus far been recognized where design modifications might significantly improve the performance of the energy system.

Solar System

1. Thermally isolate collectors from the building. Special attention should be given to this in facilities using the collectors as an integral part of the structure.
2. Reduce the effective solar storage temperature by taking advantage of the inherent storage capacity of the primary digesters and by direct use of the solar loop to preheat make-up air.
3. Isolate the solar storage from the auxiliary heating controls to expand the storage temperature range particularly in the unoccupied periods.

Heat Pump

1. Size effluent pick up tank to minimize drawdown problems associated with plant flow variations.
2. Design effluent side to facilitate normal maintenance.

Instrumentation

1. Keep instrumentation as simple as possible. The instrumentation tends to become complicated when integrating solar and perhaps other alternative energy systems with the heating, ventilating and processes of the treatment plant.

Digester Gas System Design

The Wilton wastewater treatment plant's energy systems design has received a great deal of attention. Since the inception of the energy systems monitoring project, several reports have been written concerning the economic feasibility of solar-assisted anaerobic sludge digestion. It is the author's opinion that some of these reports are optimistic, at best, and that the operating results at Wilton do not justify this optimism.

The basis for the Wilton design is that the use of flat plate hydronic solar collectors in concert with anaerobic sludge digestions is symbiotic, that the low temperature thermal energy produced by the solar collectors can be used to heat the digesters, replacing a portion of the digester gas produced which would have to be burned to heat a similar nonsolar-assisted digester. The gas thus replaced can be stored for use as a fuel for the production of direct thermal energy (boiler), electrical energy (engine-generator), or mechanical energy (engine-drive). The cost-effectiveness of

active solar energy production is strengthened when so combined with anaerobic digestion. Its payback is quicker because the thermal energy is needed year-round to heat the sludge. Storage of solar energy is much more efficient in the form of the compressible, combustible, gas produced as a byproduct of digestion than as hot water or air. This is the rationale advanced to support the Wilton design and used to substantiate claims of widescale cost-effective applicability in other reports.

The problem with the solar digester scenario is in its cost-effectiveness; Wilton successfully demonstrates its technological feasibility. The evidence from Wilton and elsewhere indicates, however, that the payback on active solar systems is longer than anticipated due to actual operating efficiencies being significantly lower than projected from instantaneous design data efficiencies.

The other major flaw in the solar digester argument is that heat can be recovered, directly or indirectly, from the digester gas more cost-effectively than by solar. A study done by WRIGHT-PIERCE to determine possible innovative and alternative technologies for use at a wastewater treatment plant being designed for Caribou, Maine indicates that if there is sufficient sludge to justify anaerobic digestion as a stabilization process, then it is more cost-effective to 1) burn the gas to heat the digesters; 2) use the gas to fuel an engine generator set to produce electricity and recover the heat given off by the engine to provide digester heating; or 3) fuel an engine-drive set to operate equipment (replacing electricity), with engine heat recovery. If there is sufficient gas produced to justify sludge digester, then the heat recovered from any of the above systems will more than offset any feasible solar contribution. If there is not sufficient sludge to make anaerobic digestion cost-effective, then adding solar will not make it so (this is Wilton's situation).

This tentative conclusion does not refute the findings of Acurex Corporation in their report to EPA entitled "Solar Energy for Pollution Control". The Acurex authors concluded that solar heating of anaerobic digesters was the most cost-effective application for solar energy in wastewater treatment. They do not state that it is absolutely cost-effective when compared to other heating alternatives. Essentially, they say that if there is a policy commitment to using solar energy in wastewater treatment, the best use of solar energy is heating digesters. Nothing WRIGHT-PIERCE has done, either in Wilton or elsewhere, leads us to disagree. There is a great deal of difference, however, between being the most cost-effective application for solar heating, and solar heating being the most cost-effective alternative for a given application.

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APPENDIX A - Conversion Factors

Physical quantity	Conversion factor
Area	$1 \text{ ft}^2 = 0.0929 \text{ m}^2$
Density	$1 \text{ lb}_m/\text{ft}^3 = 16.018 \text{ kg/m}^3$
Heat, energy, or work	$1 \text{ Btu} = 1055.1 \text{ J}$ $1 \text{ cal} = 4.186 \text{ J}$ $1 \text{ hp} \cdot \text{hr} = 2.685 \times 10^6 \text{ J}$
Force Heat flow rate	$1 \text{ BTU/hr} = 0.2931 \text{ W}$
Heat flux	$1 \text{ BTU/hr} \cdot \text{ft}^2 = 3.1525 \text{ W/m}^2$
Heat-transfer coefficient	$1 \text{ BTU/hr} \cdot \text{ft}^2 \cdot \text{F} = 5.678 \text{ W/m}^2 \cdot \text{K}$
Length	$1 \text{ ft} = 0.3048 \text{ m}$
Mass	$1 \text{ lb}_m = 0.4536 \text{ kg}$
Mass flow rate	$1 \text{ lb}_m/\text{hr} = 0.000126 \text{ kg/sec}$
Power	$1 \text{ hp} = 745.7 \text{ W}$ $1 \text{ BTU/hr} = 0.293 \text{ W}$
Pressure	$1 \text{ lb f/in}^2 = 6894.8 \text{ Pa (N/m}^2)$
Radiation	$1 \text{ langley} = 41,860 \text{ J/m}^2$
Specific heat capacity	$1 \text{ BTU/lb}_m \cdot ^\circ\text{F} = 4187 \text{ J/kg} \cdot \text{K}$
Internal energy or enthalpy	$1 \text{ BTU/lb} = 2326.0 \text{ J/kg}$ $1 \text{ cal/g} = 4184 \text{ J/kg}$
Temperature	$T (^\circ\text{F}) = (T (^\circ\text{C})) (9/5) + 32$
Thermal conductivity	$1 \text{ BTU/hr} \cdot \text{ft} \cdot ^\circ\text{F} = 1.731 \text{ W/m} \cdot \text{K}$
Thermal resistance	$1 \text{ hr} \cdot ^\circ\text{F/Btu} = 1.8958 \text{ K/W}$
Velocity	$1 \text{ ft/sec} = 0.3048 \text{ m/sec}$ $1 \text{ mi/hr} = 0.44703 \text{ m/sec}$
Viscosity, dynamic	$1 \text{ lb}_m/\text{ft} \cdot \text{sec} = 1.488 \text{ N}_2 \cdot \text{sec/m}^2$ $1 \text{ cP} = 0.00100 \text{ N} \cdot \text{sec/m}^2$
Visosity, kinematic	$1 \text{ ft}^2/\text{sec} = 0.09029 \text{ m}^2/\text{sec}$ $1 \text{ ft}^2/\text{hr} = 2.581 \times 10^{-5} \text{ m}^2/\text{sec}$
Volume	$1 \text{ ft}^3 = 0.02832 \text{ m}^3$ $1 \text{ gal (U.S. liq.)} = 0.003785 \text{ m}^3$
Volumetric flow rate	$1 \text{ ft}^3/\text{min} = 0.000472 \text{ m}^3/\text{sec}$

APPENDIX B BUILDING "U" FACTORS

BUILDING AREA	FLOOR AREA (FT ²)	U (BTUH/FT ² -°F)	ROOF AREA (FT ²)	U (BTUH/FT ² -°F)	WALL AREA (FT ²)	U (BTUH/FT ² -°F)	GLASS AREA (FT ²)	U (BTUH/FT ² -°F)	SC	LIGHTING (KW)	MISC (KW)	INFILTRATION (CFM)
CLERIFIER AREA	2745	0.10	4278	0.051	N - 584 W - 456	0.091 0.091	S - 896 N - 36	0.29 0.60	0.66 (T) 0.20			
OFFICE - TRUCK AREA	3088	0.10	1958	0.070	N - 1174 E - 737 W - 79	0.083 0.083 0.083	N - 261 E - 63 E (DOOR) - 153	0.57 0.24 0.20	0.23 0.55			183
DIGESTERS (EACH)	425	0.10	415 EA	0.05	OA - 305 INT - 260 GND - 447	0.083 0.083 0.083						
ACTIVE SOLAR COLLECTORS TOWER					60° ± HORIZ 2124 N - 1929	0.039 0.091						

APPENDIX C

DESIGN AND ACTUAL TEMPERATURES (OUTSIDE AIR AND GROUND*)

Month	Design (°C)		ACTUAL (°C)	
	OA	Ground	OA	Ground
January	-7.8	6.7	-6.7	7.8
February	-6.7	5.6	-7.9	6.7
March	-1.1	7.2	-1.2	6.1
April	5.6	10.0	-	-
May	11.7	13.3	-	-
June	17.2	16.1	16.6	14.6
July	20.0	18.9	21.6	17.2
August	18.9	19.4	16.9	19.2
September	14.4	18.3	12.4	18.5
October	8.9	15.6	7.7	15.9
November	2.8	12.2	4.6	12.9
December	-1.1	8.9	-3.7	10.1

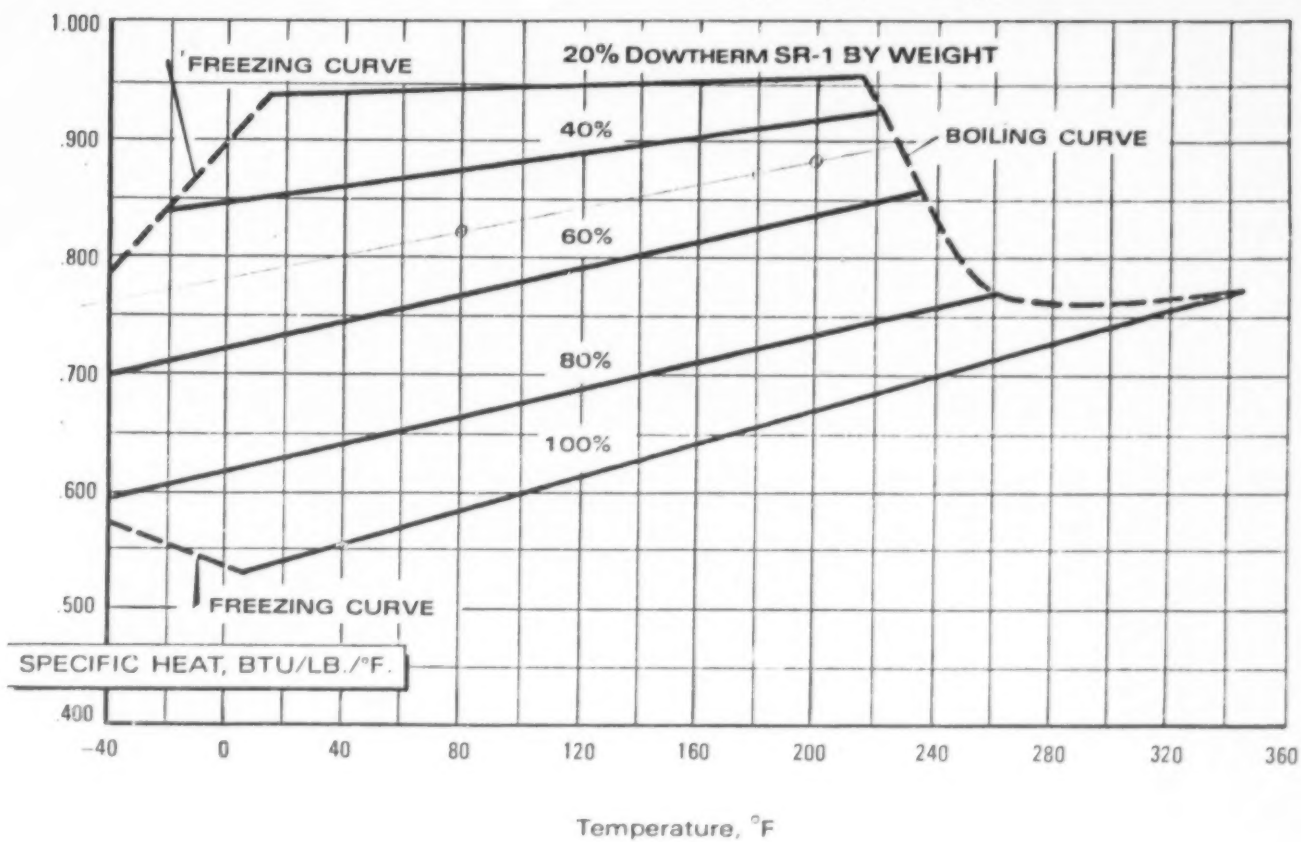
* Taken as ground water temperature or plant influent temperature.

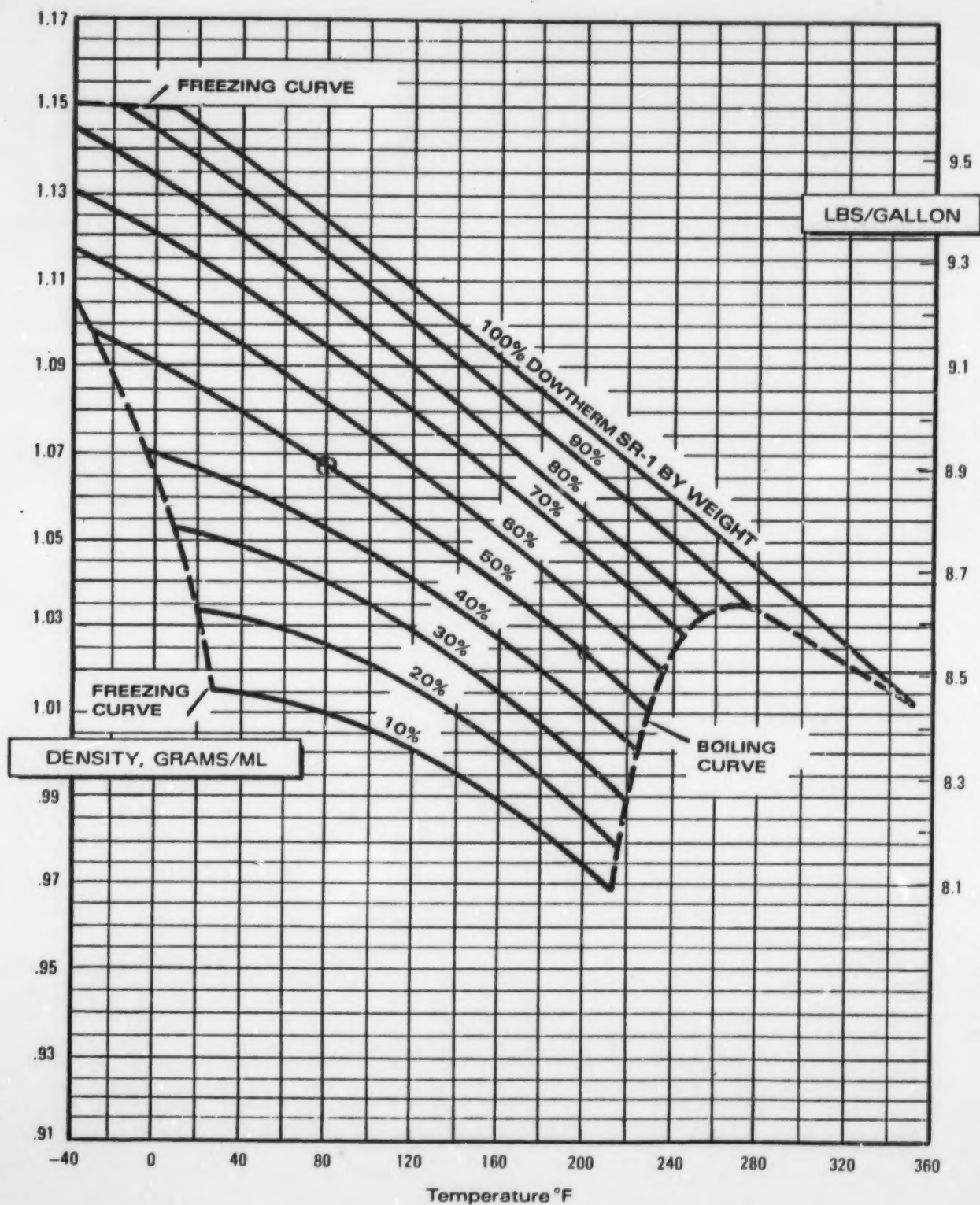
APPENDIX D

ELECTRICAL EQUIPMENT DATA AND OPERATING SCHEDULES									
DESCRIPTION	LOADING DATA		OPERATING DATA			REACTING DATA		MISC.	
	HP	KVA	F	PHASE	Δ	MIN. SP	MAX. SP		
HEATING & VENTILATING									
HEATING			400	1	400/100	8	5		2000 CFM OA
HV-1	2		400	1	400/100	8	5		2700 CFM OA
HV-2	4		400	1	400/100	8	5		900 CFM OA
UM-1	100								
UM-2	100								
UM-3	100								
UM-4	100								
UM-5	100								
UM-6	100								
UM-7	100								
UM-8	140								
UM-9	140								
UM-10	140								
UM-11	140								
UM-12	140		120	1		8	5		300 CFM OA
UM-13	140								
UM-14	140								
UM-15	140								
UM-16	140								
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UM-19	140								
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APPENDIX E

DOWTHERM SR-1 SPECIFIC HEAT AND DENSITY CURVES





APPENDIX F

ASHRAE MEAN PERCENTAGE OF POSSIBLE SUNSHINE
FOR SELECTED LOCATIONS

MEAN PERCENTAGE OF POSSIBLE SUNSHINE FOR SELECTED LOCATIONS												
STATE AND STATION	YEARS	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	ANNUAL
ALA. BIRMINGHAM	56	43	49	56	63	66	67	62	65	66	67	59
MONTGOMERY	49	51	53	61	69	73	72	66	69	69	71	64
ALASKA, ANCHORAGE	19	39	46	56	58	50	51	45	39	35	32	29
FAIRBANKS	20	34	50	61	68	55	53	45	35	31	28	29
JUNEAU	14	30	32	39	37	34	35	28	30	25	18	30
NOME	29	44	46	48	53	51	48	32	26	34	35	30
ARIZ. PHOENIX	64	76	79	83	88	93	94	84	84	89	88	77
YUMA	52	83	87	91	94	97	98	92	91	93	93	91
ARK. LITTLE ROCK	66	44	53	57	62	67	72	71	73	71	74	62
CALIF. EUREKA	49	40	44	50	53	54	56	51	46	52	48	49
FRESNO	55	46	63	72	83	89	94	97	97	93	87	73
LOS ANGELES	63	70	69	70	67	68	69	80	81	80	76	72
RED BLUFF	39	50	60	65	75	79	86	95	94	89	77	64
SACRAMENTO	48	44	57	67	76	82	90	96	95	92	82	65
SAN DIEGO	68	68	67	68	66	60	60	67	70	70	76	71
SAN FRANCISCO	64	53	57	63	69	70	75	68	63	70	70	62
COLO. DENVER	64	67	67	65	63	61	69	68	68	71	71	67
GRAND JUNCTION	57	58	62	64	67	71	79	76	72	77	74	67
CONN. HARTFORD	48	46	55	56	54	57	60	62	60	57	55	46
D. C. WASHINGTON	66	46	53	56	57	61	64	64	62	62	61	54
FLA. APALACHICOLA	26	59	62	62	71	77	70	64	63	62	74	66
JACKSONVILLE	60	58	59	66	71	71	63	62	63	58	58	53
KEY WEST	45	68	75	78	78	76	70	69	71	65	65	69
MIAMI BEACH	48	66	72	73	73	68	62	65	67	62	62	65
TAMPA	63	63	67	71	74	75	66	61	64	64	67	61
GA. ATLANTA	65	48	53	57	65	68	68	62	63	65	67	60
HAWAII, HILO	9	48	42	41	34	31	41	44	38	42	41	34
HONOLULU	53	62	64	60	62	64	66	67	70	70	68	63
LIHUE	9	48	48	48	46	51	60	58	59	67	58	49
IDAHO, BOISE	20	40	48	59	67	68	75	89	86	81	66	46
POCATELLO	21	37	47	58	64	66	72	82	81	78	66	46
ILL. C. CHICAGO	30	46	53	59	65	71	77	82	79	75	73	58
SPRINGFIELD	66	44	49	53	56	63	69	73	70	65	61	47
IND. EVANSVILLE	59	47	51	54	58	64	69	76	72	73	64	53
FT. WAYNE	48	42	49	55	61	67	73	78	76	73	67	52
INDIANAPOLIS	48	38	44	51	55	62	69	74	69	64	58	41
IOWA, DES MOINES	83	41	47	49	55	62	68	74	70	68	64	39
DUBUQUE	66	56	56	56	59	62	66	75	70	64	64	53
SIOUX CITY	54	48	52	52	58	60	63	73	67	61	55	44
KANS. CONCORDIA	52	55	58	58	59	63	67	75	72	67	65	53
DODGE CITY	52	60	60	62	63	65	73	79	76	72	70	64
WICHITA	70	67	66	68	68	68	74	78	78	76	75	67
KY. LOUISVILLE	46	61	63	64	64	66	73	80	77	73	69	67
LA. NEW ORLEANS	59	41	47	52	57	64	68	72	69	68	64	51
SHREVEPORT	69	49	50	57	63	66	64	58	60	64	70	60
MAINE, EASTPORT	18	48	54	58	60	69	78	79	80	79	77	65
MASS. BOSTON	58	45	51	52	52	51	53	55	57	54	50	37
MICH. ALPENA	67	47	56	57	56	59	62	64	63	61	58	48
DETROIT	45	29	43	52	56	59	64	70	64	52	44	24
GRAND RAPIDS	69	34	42	48	52	58	65	69	66	61	54	35
MARQUETTE	56	26	37	48	54	60	66	72	67	58	50	31
S. STE. MARIE	55	31	40	47	52	53	56	63	57	47	38	24
MINN. DULUTH	60	28	44	50	54	54	59	63	58	45	36	21
MINNEAPOLIS	49	47	55	60	58	58	60	68	63	53	47	36
MISS. VICKSBURG	45	49	54	55	57	60	64	72	69	60	54	40
MO. KANSAS CITY	66	46	50	57	64	69	73	69	72	74	71	60
ST. LOUIS	69	55	57	59	60	64	70	76	73	70	67	59
SPRINGFIELD	68	48	49	56	59	64	68	72	68	67	65	54
MONT. HAVRE	45	48	54	57	60	63	69	77	72	71	65	58
HELENA	55	49	58	61	63	63	65	78	75	64	57	48
KALISPELL	65	46	55	58	60	69	73	77	74	63	57	48
NEBR. LINCOLN	50	28	40	49	57	58	60	77	73	61	50	28
NORTH PLATTE	55	57	59	60	60	63	69	76	71	67	66	59
NEV. ELY	53	63	63	64	62	64	72	78	74	72	70	62
LAS VEGAS	21	61	64	68	65	67	79	79	81	81	73	67
RENO	19	74	77	78	81	85	91	84	86	92	84	83
WINNEMUCCA	51	59	64	69	75	77	82	90	89	86	76	68
H. H. CONCORD	53	52	60	64	70	76	83	90	90	86	75	62
N. J. ATLANTIC CITY	44	48	53	55	53	51	56	57	58	55	50	43
	62	51	57	58	59	62	65	67	65	65	54	52

MEAN PERCENTAGE OF POSSIBLE SUNSHINE FOR SELECTED LOCATIONS												
STATE AND STATION	YEARS	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	ANNUAL
N. MEX. ALBUQUERQUE	28	70	72	72	76	79	84	76	75	81	80	79
ROSWELL	47	69	72	75	77	76	80	76	75	74	74	69
N. Y. ALBANY	63	43	51	53	53	57	62	63	61	58	54	39
BINGHAMTON	63	31	39	41	44	50	56	54	51	47	43	29
BUFFALO	49	32	41	49	51	59	67	70	67	60	51	31
CANTON	43	37	47	50	48	54	61	63	61	54	45	30
NEW YORK	83	49	56	57	59	62	65	66	64	64	61	53
SYRACUSE	49	31	38	45	50	58	64	67	63	56	47	29
N. C. ASHEVILLE	57	48	53	56	61	64	63	59	59	62	64	59
RALEIGH	61	50	56	59	64	67	65	62	62	63	64	62
N. DAK. BISMARCK	65	52	58	56	57	58	61	73	69	62	59	49
DEVILS LAKE	55	53	60	59	60	56	62	71	67	59	56	44
FARGO	39	47	55	56	58	62	63	73	69	60	57	39
WILLISTON	43	51	59	60	63	66	66	78	75	85	80	48
OHIO, CINCINNATI	44	41	46	52	56	62	69	72	68	68	60	46
CLEVELAND	65	29	36	45	52	51	67	71	68	62	54	32
COLUMBUS	65	36	44	49	54	63	68	71	68	66	60	44
OKLA. OKLAHOMA CITY	62	57	60	63	64	65	74	78	74	68	64	57
OREG. BAKER	46	41	49	56	61	63	67	83	81	74	62	46
PORTLAND	69	27	34	41	49	52	55	70	65	55	42	28
ROSEBURG	29	24	32	40	51	57	59	79	77	68	42	28
PA. HARRISBURG	60	43	52	55	57	61	65	68	63	62	58	47
PHILADELPHIA	66	45	56	57	58	61	62	64	61	62	61	53
PITTSBURGH	63	32	39	45	50	57	62	64	61	62	54	39
R. I. BLOCK ISLAND	48	45	54	47	56	58	60	62	62	60	59	50
S. C. CHARLESTON	61	58	60	65	72	73	70	66	66	67	68	68
COLUMBIA	55	53	57	62	68	69	68	63	65	64	68	64
S. DAK. HURON	62	55	62	60	62	65	68	76	72	66	61	52
RAPID CITY	53	58	62	63	62	61	66	73	73	69	66	58
TENN. KNOXVILLE	62	42	49	53	59	64	66	64	59	64	53	41
MEMPHIS	55	44	51	57	64	68	74	73	74	70	69	58
NASHVILLE	63	42	47	54	60	65	69	68	69	65	55	42
TEX. ABILENE	14	64	68	73	66	73	86	83	85	73	71	72
AMARILLO	54	71	71	75	75	75	82	81	75	76	76	76
AUSTIN	33	46	50	57	60	62	72	76	79	70	70	57
BROWNSVILLE	37	44	49	51	57	65	73	78	78	67	70	54
DEL RIO	36	53	55	61	63	60	66	75	80	69	66	58
EL PASO	53	74	77	81	85	87	87	78	78	80	82	80
FT. WORTH	33	56	57	65	66	67	75	78	78	74	70	63
GALVESTON	66	50	50	55	61	69	76	72	71	70	64	49
SAN ANTONIO	57	48	51	56	58	60	69	74	75	69	67	55
UTAH, SALT LAKE CITY	22	48	53	61	68	73	78	82	82	84	73	56
VT. BURLINGTON	54	34	43	48	47	53	59	62	59	51	43	25
VA. NORFOLK	60	50	57	60	63	67	66	66	66	63	64	60
RICHMOND	56	49	55	59	63	67	66	65	62	63	64	58
WASH. NORTH HEAD	44	28	37	42	48	48	48	50	46	48	41	27
SEATTLE	26	27	34	42	48	53	48	62	56	53	36	24
SPOKANE	62	26	41	53	63	64	68	82	79	68	53	28
TATOOSH ISLAND	49	26	36	39	45	47	46	48	44	47	38	26
WALLA WALLA	44	24	35	41	63	67	72	86	84	72	59	33
YAKIMA	18	34	49	62	70	72	74	86	86	74	61	38
W. VA. ELKINS	55	33	37	42	47	55	55	56	53	55	51	41
PARKERSBURG	62	30	36	42	49	56	60	63	60	60	53	37
WIS. GREEN BAY	57	44	51	55	56	58	64	70	65	58	52	40
MADISON	59	44	49	52	53	58	64	70	66	60	56	41
MILWAUKEE	59	44	48	53	56	60	65	73	67	62	56	44
WYO. CHEYENNE	63	65	66	64	61	59	68	70	68	69	69	65
LANDER	57	66	70	71	66	65	74	76	75	72	67	61
SHERIDAN	52	56	61	62	61	61	67	76	74	67	60	53
YELLOWSTONE PARK	35	39	51	55	57	56	63	73	65	57	45	38
P. R. SAN JUAN	57	64	69	71	66	59	62	65	67	61	63	65

APPENDIX G

ENERGY USAGE RECORDS

CONSTRUCTION PHASE

<u>1978</u>	<u>KWH</u>	<u>KW</u>	<u>F.A.</u>	<u>\$</u>
8-18 / 9-19		52	.0089	412.67
9-19 / 10-18	11760	42	.0130	485.22
10-18 / 11-1	7120	42		284.05

OPERATIONAL PHASE

<u>1978</u>				
11-1 / 11-16	9560	60	0.0146	384.95
11-16 / 12-18	22720	64	0.0130	838.27

1979

12-18 / 1-17	20360	60	0.0112	768.90
1-17 / 2-15	19280	64	0.0118	771.97
2-15 / 3-19	22120	64	0.0141	889.75
3-19 / 4-18	21880	60	0.0157	898.36
4-18 / 5-17	20400	60	0.0172	883.96

PROPANE USAGE

1979

	<u>GALLONS</u>	<u>\$</u>
1 - 12	651	302.15
1 - 25	535	248.15
2 - 8	501	232.23
2 - 21	100	53.40
2 - 26	886	410.88
3 - 8	381	169.12
3 - 8	57	25.18
12 - 15	1710.3	793.58
12 - 30	828	384.19

THERMOCOUPLE LOCATIONS (ACTIVE COLLECTORS)

[illegible]

APPENDIX I

HEAT PUMP SPECIFICATION DATA

- A. Total heat output: 320,000 BTUH (26.66 tons)
- B. Condenser side:
 - 1. 40 GPM heating system water.
 - 2. Leaving water temperature: 130°F.
 - 3. Entering water temperature: 114°F.
 - 4. Water pressure drop: 13.5 ft.
 - 5. Refrigerant saturated discharge temperature: 140°F.
 - 6. Electric input at full load: 28.4 KW.
 - 7. $COP = \frac{\text{Heat Output}}{\text{Electrical Input}} = 3.3$
- C. Evaporator Side:
 - 1. Fluid: Sewage effluent with 10 PPM chlorine residual and minimal suspended solids.
 - 2. Fluid Flow: 60 gpm.
 - 3. Entering Water Temperature: 50°F.
 - 4. Leaving water temperature: As required.
 - 5. Maximum water pressure drop: 5 PSI.
- D. Refrigerant: R-22.
- E. Saturated suction temperature: 36°F.
- F. Acceptable variation in performance from specified conditions:
 - 1. Total heat output: 320,000 BTUH minimum.
 - 2. Condenser water flow: None.
 - 3. Leaving condenser water temperature: None.
 - 4. COP: 3.1 minimum.
 - 5. Evaporator water flow: 80 GPM maximum.
 - 6. Leaving evaporator water temperature: 42° minimum.
 - 7. Refrigerant: Others will be acceptable providing they meet performance requirements.

APPENDIX J

DATA VERIFICATION

INTRODUCTION

The information contained herein is the procedures, data, and calculations used to verify the energy monitoring system meter calibration factors for the Wilton Wastewater Treatment Plant. These calibration factors are then used in the analysis of the data to determine the energy usage of the facility and the contribution made by each energy subsystem.

Each monitoring system will be addressed individually with design parameters and verification calculations included with each section.

All equipment operating data is either from actual measured conditions or from design conditions. Temperature readings were taken where possible with in-the-line installed thermometers. All such measured and/or design conditions appear in the respective monitoring system schematic.

SUMMARY

The ^{verified} calibration factors for all monitoring equipment is summarized below.

<u>Designation</u>	<u>Description</u>	<u>Calibration Factor</u>
<u>Btu Meters:</u>		
A	Generator to Storage	1500 Btu / ct
B	Storage to Heating	1200 "
C	Solar Production	2000 Btu / count
D	Solar to Heating	2000 "
E	Domestic Hot Water	1000 Btu / count
F	Methane Boiler	2200 "
G	Heat Pump	2200 "
H	Digester Heating	660 "
I	Building Heating	2200 "
J	HV-1 Heating	2000 Btu / count
K	HV-2 Heating	1000 Btu / count

Pyranometers:

B/A	TOTAL ACTIVE	206.98 Btu / count
BLP	TOTAL PASSIVE	205.37 Btu / count
B2	NON-REFLECTED ACTIVE	227.67 Btu / count
B3	INDOOR PASSIVE	312.51 Btu / count

Wattmeters:

Pump P-1	0.01 KWH / count
Pump P-2	0.01 KWH / count
Heat Pump	0.10 KWH / count
Domestic Hot Water	0.10 KWH / count
Generator	0.10 KWH / count

Miscellaneous:

Master Electric Meter	40 KWH / count
City Water Meter	

Bristol Meter Calibration Factors - Unverified

					Verified
B1	A	2750 cts/hr	4-20-79	AJL	✓
B2		2500 cts/hr	4-20-79	AJL	✓
B1	P	1750 cts/hr	4-20-79	AJL	✓
B3		1150 cts/hr	4-20-79	AJL	✓

BTU	"A"	1500 Btu/ct	4/20	AJL	
	"B"	1200 Btu/ct	4/20 & 5/4	AJL & PLT	
	"C"	2000 Btu/ct	5/4	PLT	✓
	"D"	2000 Btu/ct	5/4	PLT	
	"E"	1000 Btu/ct	4/20	AJL	✓
	"F"	2200 Btu/ct	4/20	AJL	
	"G"	2200 Btu/ct	5/4	PLT	
	"H"	660 Btu/ct	7/27	PLT	✓
	"I"	2200 Btu/ct			
	"J"	2000 Btu/ct	5/4	PLT	✓
	"K"	1000 Btu/ct	2/28/80	PLT	✓

KWH	Generator	0.10 KWH/ct	5/24	BHM	
KWH	Heat Pump	0.10 KWH/ct	5/24	BHM	
KWH	DHW	0.10 KWH/ct	5/24	BHM	✓
KWH	P1	0.01 KWH/ct	5/24	BHM	✓
KWH	P2	0.01 KWH/ct	5/24	BHM	✓

KWH	Master	Multiplier = 40 KWH/ct	6/1	PLT	✓
-----	--------	------------------------	-----	-----	---

B1	Pyranometer	Eppley PSP	S/N 17274F3	7.54 mv/cal/min/cm	
B2	Pyranometer	Eppley PSP	S/N 17273F3	7.26 mv/cal/min/cm	
B3	Pyranometer	Eppley PSP	S/N 17317	6.67 mv/cal/min/cm	

Methane Meters
City Water Meter

Moore Transmitter Calibrations

<u>Bta Loop</u>	<u>S/N</u>	<u>Frequency Full Scale (Hz)</u>	<u>ΔT</u>	<u>GPM</u>	<u>Range</u>
A	58379	175.5		75	B
B	58380	147.8		64.8	B
C	58383	136.4		60.0	B
D	58384	139.5		60.0	B
E	58387	133.4		5	E
F	58385	202		88	C
G	58388	200		88	C
H	58387	206		88	C
I	58386	207		88	C
J	58381	92.3		40.0	A
K	58382	190		20	B

Building Orientation

To properly evaluate the solar collector performance the actual building siting must be accurately known.

To do this, local solar noon (LS Noon) was determined and measurements were taken at that time. The calculations and results of this evaluation as that the solar collector array is facing West of South (True South) by 2.3° . All calculations for the determination will now be based upon either due south or the 2.3° W of South.

WILTON, ME, LATITUDE AND LONGITUDE:

LATITUDE = 44° North

LONGITUDE = 69° West

WILTON: SOLAR TIME CALCULATIONS

July 6, 1977

$$LST = LCT + Eq. of Time$$

$$LCT = LST - Eq. of Time$$

$$LCT = 12:00 \text{ N} - - :05 = 12:05 \text{ PM}$$

$$LCT = EST + 20 \text{ min}$$

$$EST = LCT - 20 = 12:05 - 20 = 11:45$$

$$EDST = EST + 1 \text{ hr}$$

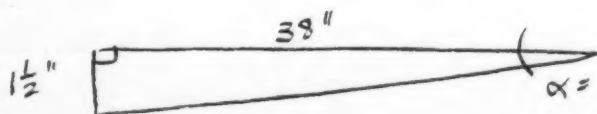
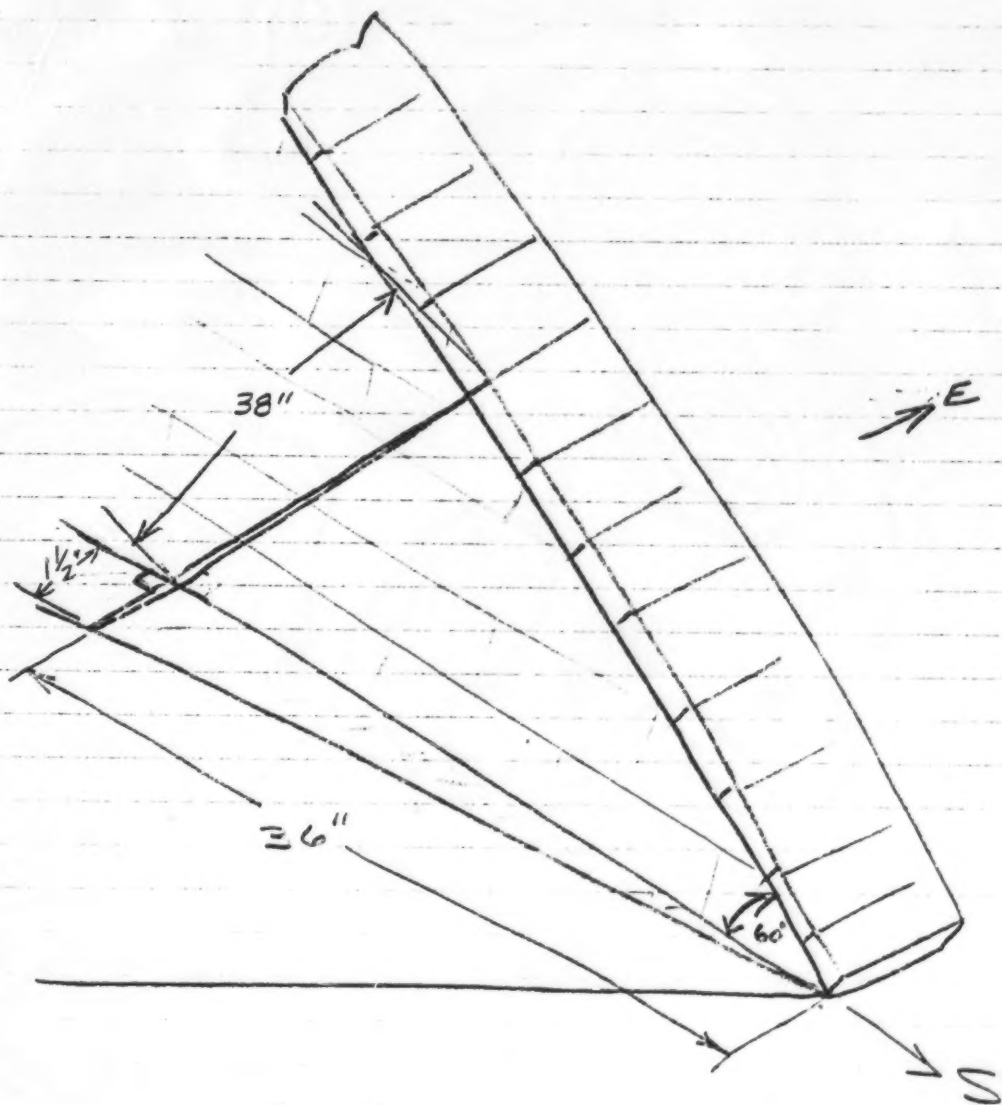
$$EDST = 11:45 + 1 \text{ hr} = \underline{12:45 \text{ PM}}$$

= Local Solar Noon

July 6, 1979 12:45 PM EDT

12:45 PM

EDST



$$\alpha = \tan^{-1} \frac{1.5}{38} = 2.3^\circ \text{ W of South}$$

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PORTSMOUTH, NEW HAMPSHIREPROJECT NO. 4795PROJECT PYRANOMETER VERIFICATION

BOOK NO. _____

Pyranometer E1

Eppley Model PSP S/N 17274F3

Calibration Data : $10.81 \times 10^{-6} \text{ V/Wm}^{-2}$
(7.54 mv/cal/cm².min)Pyranometer E2

Eppley Model PSP S/N 17273F3

Calibration Data : $10.41 \times 10^{-6} \text{ V/Wm}^{-2}$
(7.26 mv/cal/cm².min)Pyranometer E3

Eppley Model PSP S/N 17317F3

Calibration Data : $9.56 \times 10^{-6} \text{ V/Wm}^{-2}$
(6.67 mv/cal/cm².min)

E1 Active Meter Calibration	2750 cts/hr	Full Scale
E1 Passive Meter Calibration	1750 cts/hr	Full Scale
E2 (Shielded) Meter Calibration	2500 cts/hr	Full Scale
E3 (Interior) Meter Calibration	1150 cts/hr	Full Scale

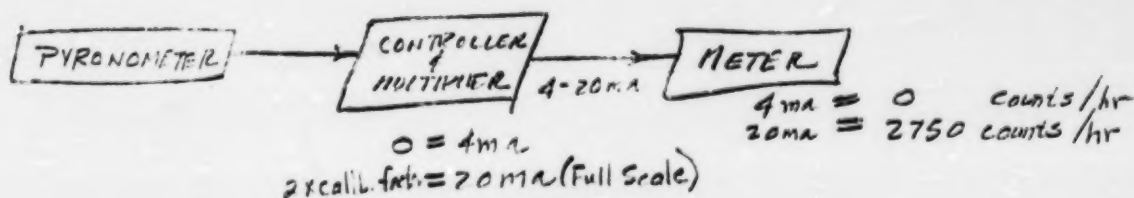
Effective Active Solar Area = 1286 ft²Effective Passive Solar Area = 212 ft²

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BOOK NO. _____



To calibrate the metering system
take 2 times the pyrometer calibration
as the full scale reading level.

$$2 \text{ cal/min-cm}^2 = 442.6 \text{ Btu-h/ft}^2$$

B-1 Active

$$\begin{aligned}
 2750 \text{ counts/hr} &= 2 \text{ cal/cm}^2\text{-min} = 442.6 \text{ Btu-h/ft}^2 \\
 &= 442.6 \times 1286 = 569,184 \text{ Btu-h}
 \end{aligned}$$

$$\frac{569,184 \text{ Btu-h}}{2750 \text{ counts/hr}} = 206.98 \text{ Btu/count}$$

B-1 Passive

$$\begin{aligned}
 1750 \text{ counts/hr} &= 2 \text{ cal/cm}^2\text{-min} = 442.6 \text{ Btu-h/ft}^2 \\
 &= 442.6 \times 812 = 359,391 \text{ Btu-h}
 \end{aligned}$$

$$\frac{359,391 \text{ Btu-h}}{1750 \text{ counts/hr}} = 205.37 \text{ Btu/count}$$

BY HT DATE _____

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CHKD. BY _____ DATE _____

PROJECT NO. 4795

PROJECT PYROMETER VERIFICATION

BOOK NO. _____

B-2 Shielded

$$\begin{aligned} 2500 \text{ counts/hr} &= 2 \text{ cal/cm}^2\text{-min} = 442.6 \text{ Btu/h/ft}^2 \\ &= 442.6 \times 1286 = 569,184 \text{ Btu/h} \end{aligned}$$

$$\frac{569,184 \text{ Btu/h}}{2500 \text{ counts/hr}} = 227.67 \text{ Btu/count}$$

B-2 Indoor

$$\begin{aligned} 1150 \text{ counts/hr} &= 2 \text{ cal/cm}^2\text{-min} = 442.6 \text{ Btu/h/ft}^2 \\ &= 442.6 \times 812 = 359,391 \text{ Btu/h} \end{aligned}$$

$$\frac{359,391 \text{ Btu/h}}{1150 \text{ counts/hr}} = 312.51$$

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CHKD. BY _____ DATE _____

PROJECT NO. 4795PROJECT PYRCHLIFTER VERIFICATION

BOOK NO. _____

For this day solar noon corresponds to 12:41 PM EST. The solar insolation data, as tabulated in Appendix 2, is listed as the insolation intercepted from 30 min before to 30 min after the local hour where hour 12 corresponds to the insolation received from 11:30 AM to 12:30 PM EST.

The following table gives the total insolation anticipated and measured for the various hours.

B1 Active

<u>Hour (EST)</u>	<u>Insolation from Tables (Btu/h/ft²)</u>	<u>Insolation from Pyranometer (Btu/h/ft²)</u>
10	207.0	204.4
11	234.5	217.6
12	244.0	210.2
1	234.5	222.1
2	207.0	196.4
5 Hr Avg.	225.4	210.1

$$\% \text{ Difference} = \left(\frac{225.4 - 210.1}{225.4} \right) \times 100 = 6.8\%$$

The tabulated data is for a clear sky. As can be seen from the pyranometer strip chart, there were occasional clouds. Also, there was a lot of haze in the air. Therefore, this pyranometer appears to be operating properly.

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BOOK NO. _____

B 1 Passive

B1 Active and B1 Passive should be identical on a Btu/lb/ft² basis since they are the same pyronometer.

<u>Hour</u>	<u>B1 Active (Btu/lb/ft²)</u>	<u>B1 Passive (Btu/lb/ft²)</u>
10	204.1	207.4
11	217.6	221.1
12	210.2	213.0
1	222.1	225.6
2	<u>196.1</u>	<u>199.3</u>
5 Hr Avg.	210.1	213.3

$$\% \text{ Difference} = \left(\frac{210.1 - 213.3}{210.1} \right) \times 100 = -1.5 \%$$

This difference is obviously due to the equipment accuracy since we are using the same pyronometer. This error is not bad though. We could correct for this if later data makes it appear that this is a constant difference. But for now, the B1 Passive meter appears to be operating properly.

BY PLT DATE 6-15-79

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SHEET NO. 6 OF 7

CHKD. BY _____ DATE _____

PROJECT NO. 4795PROJECT PYROMETER VERIFICATION

BOOK NO. _____

BZ Active (Shielded)

B1 Active and BZ with the shield removed should be equal.

<u>Hour</u>	<u>B1 Active (Btu/h/ft²)</u>	<u>BZ Active (Btu/h/ft²)</u>
11	217.6	210.7
12	210.2	202.7
1	<u>227.1</u>	<u>215.6</u>
3 Hr Avg.	216.6	209.7

$$\% \text{ Difference} = \left(\frac{216.6 - 209.7}{216.6} \right) \times 100 = +3.2\%$$

This difference is due to the equipment accuracy and possibly a bit due to additional reflection on the bottom pyrometer, B1.

BZ with the shield in place should be lower than B1 Active by the amount of reflection.

	<u>B1A (Btu/ft²-day)</u>	<u>BZ (Btu/ft²-day)</u>
June 14 Data	1947	1724
June 15 Data	1941	1744
Average	<u>1944</u>	<u>1734</u>

$$\% \text{ Difference} = \left(\frac{1944 - 1734}{1944} \right) \times 100 = 10.8\%$$

$$10.8\% - 3.2\% = 7.6\% \text{ due to reflection. This seems}$$

reasonable, therefore BZ appears to be operating properly.

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CHCKD. BY _____ DATE _____

PROJECT NO. 4795PROJECT PYRANOMETER VERIFICATION

BOOK NO. _____

B3 (Indoor)

E1 Passive and B3 should be equal were the passive panels removed and the sky diffuse of E1 Passive eliminated. To estimate the E1 Passive value we used the shield on B2 raised to the overhead position. Then use the B2 data, with the appropriate scale factors, to simulate the E1 Passive.

B2 (Upper Shielded) at 2 pm, 6-15-79 Data,
is 182.9 Btu/h/ft².

B3 (Indoor) at 2 pm, 6-15-79 Data,
is 176.3 Btu/h/ft².

$$\% \text{ Difference} = \left(\frac{182.9 - 176.3}{182.9} \right) \times 100 = 3.6 \%$$

Taking the % differences into account the % Difference between B2 (Unshielded) and B3 (Indoor) is $3.6 - 3.2 - 1.5 = -1.1\%$.

Thus it would appear that B3 is operating properly, and that the errors are equipment accuracy errors and especially in this case because the shielding was not perfect and the reflections of the two are not identical.

BY PLT DATE 6-1-79

Wright, Pierce, Barnes & Wyman
ENGINEERS
TOPSHAM, MAINE
PORTSMOUTH, NEW HAMPSHIRE

SHEET NO. _____ OF _____

CHKD. BY _____ DATE _____

PROJECT NO. 4795

PROJECT Pump P-1 KWH Meter Verification

BOOK NO. _____



Nameplate Data
1 HP
460/3 ϕ /60
1.8 A

Power Calculation:

$$\text{Power} = \text{Amp.} \times \text{Volts} \times \sqrt{3} \times \text{Power Factor}$$

Field Data:

6-1-79 From 10:05 A.M. to 4:05 P.M. = 6 hours

$$\text{Amp.} = (1.10 + 1.15 + 1.20) / 3 = 1.15 \text{ A}$$

$$\text{Power} = 1.15 \times 460 \times \sqrt{3} \times .70 \times 6 \text{ hr} / 1000 = 3.35 \text{ KWH}$$

Assume Power Factor of 0.70

$$\text{KWH meter} = (444 - 38) \times 0.01 \text{ KWH/H} = 4.06 \text{ KWH}$$

P1 KWH Meter appears to be working properly within the accuracy of our measurements and the assumption of the Power Factor.

BY PLT DATE 6-1-79

Wright, Pierce, Barnes & Wyman
ENGINEERS
TOPSHAM, MAINE
PORTSMOUTH, NEW HAMPSHIRE

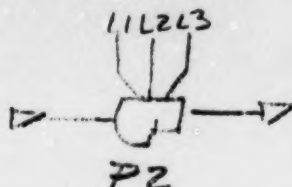
SHEET NO. _____ OF _____

CHKD. BY _____ DATE _____

PROJECT NO. 4795

PROJECT Pump P2 KWH Meter Verification

BOOK NO. _____



Nameplate Data
1 HP
460/3/60
1.8 A

Power Calculation:

$$\text{Power} = \text{Amps.} \times \text{Volts.} \times \sqrt{3} \times \text{Power Factor}$$

Field Data:

6-1-79 From 10:05 A.M. to 4:05 P.M. = 6 hrs.

$$\text{Amp.} = (1.2 + 1.2 + 1.3) / 3 = 1.23 \text{ A}$$

$$\text{Power} = 1.23 \times 460 \times \sqrt{3} \times .70 \times 6 \text{ hr} / 1000 = 4.12 \text{ KWH}$$

Assume Power Factor of 0.70

$$\text{KWH meter} = (359 - 22) \times 0.01 \text{ KWH/ct} = 3.37 \text{ KWH}$$

P2 KWH Meter appears to be working properly within the accuracy of our measurements and the assumption of the Power Factor.

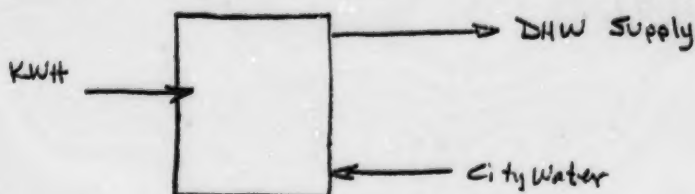
BY PLT DATE 6-8-79Wright, Pierce, Barnes & Wyman
ENGINEERS
TOPSHAM, MAINE
PORTSMOUTH, NEW HAMPSHIRE

SHEET NO. _____ OF _____

CHKD. BY _____ DATE _____

PROJECT NO. 4795PROJECT DHW KWH Meter Verification

BOOK NO. _____



DHW usage = Btu Meter "E"

Calculations: $Q_{used} = \text{Btu used according to Btu Meter "E" (previously verified)}$ $Q_{KWH} = \text{number of counts} \times \text{Meter Factor} \times 3413 \text{ Btu/KWH}$ Field Data:

6-8-79

$$Q_{used} = (74 - 11) \text{ cts} \times 1000 \text{ Btu/ct} = 63,000 \text{ Btu}$$

$$Q_{KWH} = (261 - 82) \text{ cts} \times 0.10 \text{ KWH/ct} \times 3413 \text{ Btu/KWH} = 61,093 \text{ Btu}$$

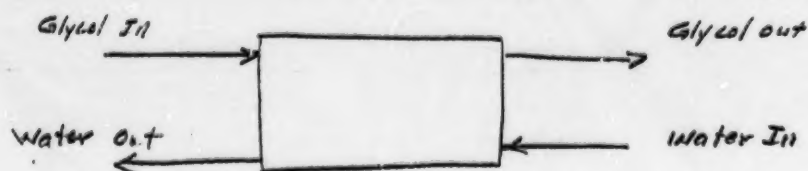
The DHW KWH Meter appears to be working properly.

BY PJT DATE 8/22/79Wright, Pierce, Barnes & Wyman
ENGINEERS
TOPSHAM, MAINE
PORTSMOUTH, NEW HAMPSHIRESHEET NO. 1 OF 3

CHCKD. BY _____ DATE _____

PROJECT NO. 4795PROJECT SOLAR PRODUCTION BTU METER VERIFICATION

BOOK NO. _____



$$\text{GPM water} = 50 \times 0.83 = 41.5 \text{ gpm}$$

HEAT BALANCE :

Water Side :

$$Q_w = 500 \times \text{gpm} \times (T_{\text{water out}} - T_{\text{water in}})$$

$$\text{Btu Meter Calibration Factor} = 2000 \text{ Btu/count}$$

BTU METER "C"

FIELD DATA :

8/22/79 From 1:15 pm to 3:00pm = $1\frac{3}{4}$ hrs

$$Q_w = 500 \times 41.5 \times (130 - 124) = 124,500 \text{ Btu/h}$$

(averaged)

$$Q_{\text{meter}} = (367 - 259) \text{ cts} \times 2000 \text{ Btu/ct} / 1\frac{3}{4} \text{ hr} = 123,430 \text{ Btu/h}$$

The meter appears to be working properly.

BY PLT DATE 10/16/79

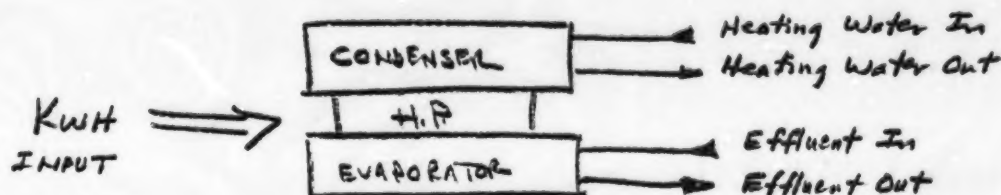
Wright, Pierce, Barnes & Wyman
ENGINEERS
TOPSHAM, MAINE
PORTSMOUTH, NEW HAMPSHIRE

SHEET NO. 1 OF

CHKD. BY DATE

PROJECT NO. 4795

PROJECT HEAT PUMP TO HEATING SYSTEM BTU METER VERIFICATION BOOK NO.



GPM Heating Water = 40 gpm

HEAT BALANCE :

Condenser Side :

$$Q = 500 \times \text{gpm} \times (T_{\text{Heating Water Out}} - T_{\text{Heating Water In}})$$

Btu Meter Calibration Factor = 2200 Btu/count
BTU METER "G"

FIELD DATA :

10/16/79 From 12:40 TO 1:20 PM

$$Q = 500 \times 40 \times (11.25) \times \frac{40}{60} = 150,000 \text{ Btu}$$

$$Q = (296 - 229) \times 2200 = 147,400 \text{ Btu}$$

The meter appears to be working properly.

BY PJT DATE 6-1-79

Wright, Pierce, Barnes & Wyman

ENGINEERS

TOPSHAM, MAINE

PORTSMOUTH, NEW HAMPSHIRE

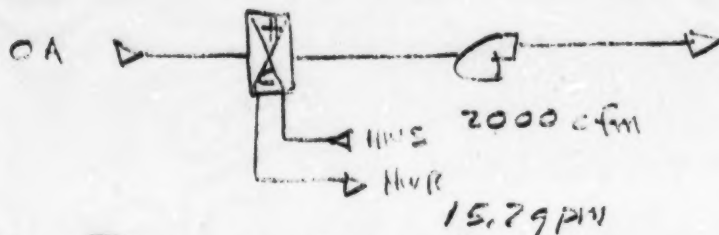
SHEET NO. _____ OF _____

CHKD. BY _____ DATE _____

PROJECT NO. 4795

PROJECT HV-1 Btu Meter Verification

BOOK NO. _____



HEAT BALANCE:

AIR SIDE:

$$Q = \text{CFM} \times 1.085 \times \Delta T \text{ (Btu/hr)}$$

BTU Meter Calibration Factor = 2000 Btu/count
BTU METER "J"

Field Data:

6-1-79 From 3:20 to 3:35 PM

$$Q = 2000 \times 1.085 \times (104 - 74) \times \frac{15 \text{ min}}{60 \text{ min/hr}} = 16,275 \text{ Btu}$$

$$\text{Btu Meter } 8 \text{ counts} \times 2000 \text{ Btu/count} = 16,000 \text{ Btu}$$

The meter appears to be working properly.

BY PLT DATE 6-1-79

Wright, Pierce, Barnes & Wyman

ENGINEERS

TOPSHAM, MAINE

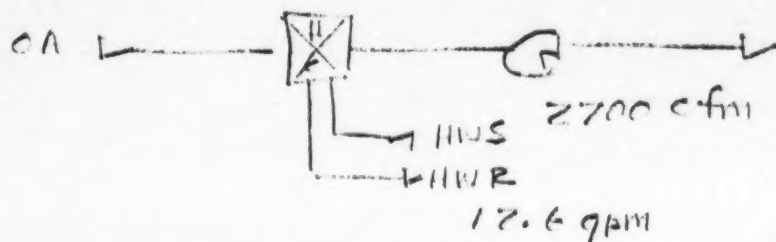
PORTSMOUTH, NEW HAMPSHIRE

SHEET NO. _____ OF _____

CHCKD. BY _____ DATE _____

PROJECT NO. 4795PROJECT HV-2. Btu Meter Verification

BOOK NO. _____

HEAT BALANCE :

AIR SIDE :

$$Q_A = \text{CFM} \times 1.085 \times (\Delta T) \quad (\text{Btu/hr})$$

WATER SIDE :

$$Q_W = 500 \times \text{GPM} \times \Delta T \quad (\text{Btu/hr})$$

BTU Meter Calibration Factor = 2000 Btu/count
BTU METER "K"Field Data :

6-1-79 from 2:40 PM to 2:55 PM

$$Q_A = 2700 \times 1.085 \times (94 - 74) \times \frac{15}{60} = 14,648 \text{ Btu}$$

$$Q_W = 500 \times 12.6 \times (109 - 100) \times \frac{15}{60} = 14,175 \text{ Btu}$$

$$\text{BTU Meter } 7 \text{ counts} \times 2000 = 14,000 \text{ Btu}$$

The meter appears to be working properly.

BY PLT DATE 6-1-79

Wright, Pierce, Barnes & Wyman

ENGINEERS

TOPSHAM, MAINE

PORTSMOUTH, NEW HAMPSHIRE

SHEET NO. _____ OF _____

CHCKD. BY _____ DATE _____

PROJECT NO. 4795PROJECT Notes on Meter Verifications

BOOK NO. _____

1. The kWh Meter verification tests were conducted taking the amperages of each leg on an instantaneous basis and assuming a power factor. The results of these tests were to verify that the meters were working within reasonable limits. Due to the low running amperage compared with the full load amperage, the power factors are quite low and difficult to estimate.

BY PLT DATE 5-4-79

Wright, Pierce, Barnes & Wyman
ENGINEERS
TOPSHAM, MAINE
PORTSMOUTH, NEW HAMPSHIRE

SHEET NO. _____ OF _____

CHKD. BY _____ DATE _____

PROJECT NO. 4795

PROJECT VERIFICATION DATA

BOOK NO. _____

DOMESTIC HOT WATER :

GPM Estimate = 4 (40 sec / 10 gal. bucket)
DHW = 130F (70 sec / 5 gal can)

CITY WATER = 55F

DHW BTU METER READING

TIME

0
69

2:25 PM
2:55 PM

WILTON, MAINE

MONITORING END PROGRAM DATA

YEAR 1979

DATA POINT	MONTH DAY	6 1	6 1	6 1	6 1	6 1	6 1	6 1
	TIME	9:05A	10:05A	11:05A	12:05P	1:05P	2:05P	3:05P
GENERATOR TO STORAGE (BTU)		0	0	0	0	0	0	0
STORAGE TO HEATING SYSTEM (BTU)		0	0	0	37	135	238	345
SOLAR TO HEATING SYSTEM (BTU)		0	0	0	0	0	0	0
DOMESTIC HOT WATER USE (BTU)		2	2	2	3	4	5	14
METHANE BOILER TO HEATING SYSTEM (BTU)		24	24	24	24	24	24	24
HEAT PUMP TO HEATING SYSTEM (BTU)		0	0	0	0	0	0	0
BUILDING HEATING SYSTEM CONSUMPTION (BTU)		0	0	0	0	0	0	0
HV-1 CONSUMPTION (BTU)		0	0	0	0	0	0	0
24 HOUR TOTAL		-	-	-	-	-	-	-
AMBIENT TEMP. SYSTEM LIGHT ONLY		-	-	-	-	-	-	-
NO. OF INTERVALS		-	-	-	-	-	-	-
B1 ACTIVE (BTU)		924	1902	3218	4768	6286	7704	9178
B2 ACTIVE (BTU)		677	1522	2675	4042	5383	6636	7932
SOLAR PRODUCTION (BTU)		0	9	65	143	226	296	377
SLUDGE FLOW INTO DIGESTER (GPM)		-	1448	2313	2609	2896	3182	3477
SLUDGE FLOW OUT OF DIGESTER (GPM)		0	0	0	0	0	0	0
DIGESTER HEATING CONSUMPTION (BTU)		1	1	1	15	56	100	135
B1 PASSIVE (BTU)		604	1238	2085	3088	4061	4981	5932
B3 PASSIVE (BTU)		0	27	161	369	585	766	963
HV-2 CONSUMPTION (BTU)		0	0	0	0	0	0	0
GENERATOR POWER CONSUMPTION (KWH)		0	0	0	0	0	0	0
HEAT PUMP POWER CONSUMPTION (KWH)		0	0	0	0	0	0	0
DHW HEATER POWER CONSUMPTION (KWH)		11	16	21	28	28	34	47
PUMP#1 POWER CONSUMPTION (KWH)		0	38	105	174	240	307	376
PUMP#2 POWER CONSUMPTION (KWH)		0	22	78	155	190	245	303

WILTON, MAINEMONITORING E&D
PROGRAM DATAYEAR 1979

DATA POINT	MONTH	DAY						
	TIME		6	1				
	4:05P							
GENERATOR TO STORAGE (BTU)			0					
STORAGE TO HEATING SYSTEM (BTU)			480					
SOLAR TO HEATING SYSTEM (BTU)			0					
DOMESTIC HOT WATER USE (BTU)			14					
METHANE BOILER TO HEATING SYSTEM (BTU)			24					
HEAT PUMP TO HEATING SYSTEM (BTU)			0					
BUILDING HEATING SYSTEM CONSUMPTION (BTU)			0					
HV-1 CONSUMPTION (BTU)			8					
24 HOUR TOTAL			-					
AMBIENT TEMP. SYSTEM LIGHT ONLY			-					
N. OF INTERVALS			-					
B1 ACTIVE (BTU)			10211					
B2 ACTIVE (BTU)			5872					
SOLAR PRODUCTION (BTU)			121					
SLUDGE FLOW INTO DIGESTER (GPM)			2768					
SLUDGE FLOW OUT OF DIGESTER (GPM)			0					
DIGESTER HEATING CONSUMPTION (BTU)			180					
B1 PASSIVE (BTU)			6596					
B3 PASSIVE (BTU)			1079					
HV-2 CONSUMPTION (BTU)			7					
GENERATOR POWER CONSUMPTION (KWH)			0					
HEAT PUMP POWER CONSUMPTION (KWH)			0					
DHW HEATER POWER CONSUMPTION (KWH)			53					
PUMP#1 POWER CONSUMPTION (KWH)			244					
PUMP#2 POWER CONSUMPTION (KWH)			350					

BY PLT DATE 6-1-79

Wright, Pierce, Barnes & Wyman

ENGINEERS

TOPSHAM, MAINE

PORTSMOUTH, NEW HAMPSHIRE

SHEET NO. _____ OF _____

CHCKD. BY _____ DATE _____

PROJECT NO. 4795PROJECT VERIFICATION DATA

BOOK NO. _____

Data Point	Time							
	9:05	9:44	11:08	12:07	1:05	2:05	3:05	4:05
<u>Multi-point Recorder</u>								
#1 Str: LWT(F)	106	106	111	117	121	124	126	124
#3 Glycol Flow(%)	0	81	81.5	81.5	81	81	81	81
#4 Stor. EWT(F)	102	101	105	109	113	115	116	112
#6 Dig. #1 (F)	94.5	94.5	94.3	94.5	94.5	94.7	95	95
#7 Solar Plate (F)	103.5	116.5	133.5	143	137	149	144	125
#9 Glycol LWT(F) (T ₂)	83	107	116	123	125	128	127	122
#12 Glycol EWT(F) (T ₁₀)	94	106	113	118	120	123	123	119
#13 Clarifier Amb(F)	64.2	65	66.5	68	68.5	69	69.5	71
<u>Misc. Readings from Control Panel</u>								
		(Time 10:17)						
T ₅ (F)	-	109	113	119	120	122	124	118
T ₁₁ (F)	-	106	109	113.5	116.5	118	119	115.5
T _{amb} (F)	-	-	68	72	74	74	74	73
T ₉ (F)	-	-	-	112	116	117	118	118

BY PLT DATE 6-1-79Wright, Pierce, Barnes & Wyman
ENGINEERS
TOPSHAM, MAINE
PORTSMOUTH, NEW HAMPSHIRE

SHEET NO. _____ OF _____

CHKD. BY _____ DATE _____

PROJECT NO. 4795PROJECT VERIFICATION DATA

BOOK NO. _____

SPECIFIC TESTSHV-1: Time OAT (F) Discharge Air Temp (F) HV-1 Btu Meter ("J")

3:20 PM

74

-

0

3:35 PM

74

104

8

HV-2: Time OAT (F) Disch. Air Temp. HWS (F) HWR (F) HV-2 Meter ("K")

3:40

74

-

109

-

0

3:55

74

94

109

100

7

PUMP P.1:Amp. Readings

L1 1.10 A

L2 1.15 A

L3 1.20 A

PUMP P.2:Amp. Readings

L1 1.20 A

L2 1.20 A

L3 1.30 A

BY PLT DATE 6-8-79

Wright, Pierce, Barnes & Wyman

ENGINEERS

TOPSHAM, MAINE

PORTSMOUTH, NEW HAMPSHIRE

SHEET NO. _____ OF _____

CHKD. BY _____ DATE _____

PROJECT NO. 4795PROJECT VERIFICATION DATA

BOOK NO. _____

SPECIFIC TESTSDHW KWH Meter

	<u>DHW Btu Meter*</u>	<u>DHW KWH Meter</u>
11:50 AM	11	82
3:50 PM	74	261

* During this test Pump P4 was deactivated, thus all the DHW used was heated by the electric heaters.

WILTON, MAINE

MONITORING END PROGRAM DATA

YEAR 1979

DATA POINT	MONTH	DAY	6/15	6/15	6/15	6/15	6/15	6/15	
		TIME	10:10	11:10	12:10	1:10	2:10	3:10	
GENERATOR TO STORAGE (BTU)			0	0	0	0	0	0	
STORAGE TO HEATING SYSTEM (BTU)			489	489	534	535	615	709	
SOLAR TO HEATING SYSTEM (BTU)			0	0	0	0	0	0	
DOMESTIC HOT WATER USE (BTU)			2	2	2	3	3	3	
METHANE BOILER TO HEATING SYSTEM (BTU)			40	40	40	40	40	40	
HEAT PUMP TO HEATING SYSTEM (BTU)			1	1	2	2	2	2	
BUILDING HEATING SYSTEM CONSUMPTION (BTU)			5	5	5	5	5	5	
HV-2 CONSUMPTION (BTU)			0	0	0	0	0	0	
24 HOUR TOTAL			0	0	0	0	0	0	
AMBIENT TEMP. SYSTEM LIGHT ONLY			0	0	0	0	0	0	
(% OF INTERVALS			216	216	216	216	216	216	
B1 ACTIVE (BTU)			14043	15313	16665	17971	19351	20571	
B2 ACTIVE (BTU)			11405	12507	13698	14843	16061	17094	NOTES 1,2,3
SOLAR PRODUCTION (BTU)			346	398	450	477	518	525	
SLUDGE FLOW INTO DIGESTER (GAL)			8492	8776	9360	10277	11162	11818	
SLUDGE FLOW OUT OF DIGESTER (GAL)			0	0	0	0	0	0	
DIGESTER HEATING CONSUMPTION (BTU)			180	180	190	190	228	268	
B1 PASSIVE (BTU)			9079	9899	10773	11645	12507	13295	
B3 PASSIVE (BTU)			1233	1465	2001	2492	3023	3481	
HV-1 CONSUMPTION (BTU)			0	0	0	0	0	0	
GENERATOR POWER CONSUMPTION (KWH)			0	0	0	0	0	0	
HEAT PUMP POWER CONSUMPTION (KWH)			34	34	63	94	94	94	
DHW HEATER POWER CONSUMPTION (KWH)			103	108	108	113	118	118	
PUMP#1 POWER CONSUMPTION (KWH)			756	823	892	961	1028	1095	
PUMP#2 POWER CONSUMPTION (KWH)			543	598	654	712	767	824	

NOTES: 1) SHIELD REMOVED FROM B2 FROM 10:45 AM TO 2:10 PM.

2) SHIELD REPLACED IN UPPER QUADRANT OF B2 TO SIMULATE B3 INSOLATION INCIDENT FROM 2:10 PM TO 3:10 PM.

3) SHIELD RETURNED TO NORMAL POSITION ON B2 AT 3:10 PM.

BY PLTDATE 8/22/79Wright, Pierce, Barnes & Wyman
ENGINEERSSHEET NO. 3 OF 3

CHKD. BY _____ DATE _____

TOPSHAM, MAINE
PORTSMOUTH, NEW HAMPSHIREPROJECT NO. 4795PROJECT WILTON MONITORING DATA

BOOK NO. _____

DATA POINT	TIME, PM (EDST)									
	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00
B1 ACTIVE	5941	6322	6790	7197	7603	8036	8390	8740	8864	9127
B2 ACTIVE	4922	5257	5667	6024	6374	6761	7071	7374	7472	7693
SOLAR PRODUCTION	213	232	259	281	305	326	347	366	367	367
B1 PASSIVE	3840	4090	4393	4656	4917	5197	5425	5648	5729	5900
B3 PASSIVE	677	747	833	909	980	1054	1104	1151	1165	1206
PUMP P1 POWER	206	220	238	253	270	286	302	318	334	352
PUMP P2 POWER	180	193	208	221	236	249	263	277	290	306
MULTI POINT READINGS										
PLATE TEMP. #7	134	148	146	148	147	145	150	140	134	146
GLYCOL LWT #9 (T _E)	124	130 (134 T _{meter})	130	132	132	135	135	135	128	134
GLYCOL EWT #12 (T ₁₀)	116	120 (124 T _{meter})	121	122	123	126	126	127	125	129
MISCELL. HEAT EXCH. (Thermistor) IN			116	118	121	123	124	127	130	135
OUT Glycol %Flow			128 83	130 83	131 83	134 83	133 83	130 83	129 83	128 83
OAT	75	75	76	76	76	77	77	76	76	77

BY PLT DATE 10/10/79 Wright, Pierce, Barnes & Wyman
ENGINEERS
TOPSHAM, MAINE
PORTSMOUTH, NEW HAMPSHIRE

SHEET NO. _____ OF _____

PROJECT NO. 4795

PROJECT VERIFICATION DATA

BOOK NO. _____

SPECIFIC TESTS

Heat Pump to Heating System Btu Meter

<u>Time</u>	<u>HP Btu "G"</u>	<u>Digester Htg Btu "H"</u>	<u>Heat Pump kWh</u>	<u>THP in</u>	<u>THP out</u>
12:36	221	64	446	88	88
12:40	229	64	462	92	104
12:45	240	67	481	98	110
12:50	253	72	503	105	116
1:00	273	75	539	112	122
1:10	288	75	570	116	122
1:20	296	75	590	116	121

BY AJL DATE 2/6/80

Wright, Pierce, Barnes & Wyman
ENGINEERS
TOPSHAM, MAINE
PORTSMOUTH, NEW HAMPSHIRE

SHEET NO. _____ OF _____

CHKD. BY _____ DATE _____

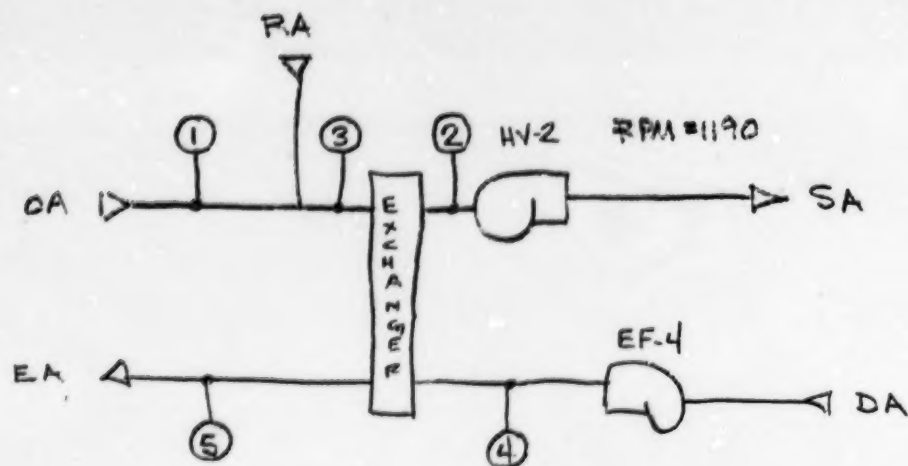
PROJECT NO. 4795

PROJECT VERIFICATION DATA

BOOK NO. _____

SPECIFIC TESTS

AIR-TO-AIR HEAT EXCHANGER ON HV-2



100% OA @ 21.5 ft/min

Point =	1	2	3	4	5
Temp. (°F)	62	50	34	58	40
S.P. ("w.c.)		0.96	0.09	0.37	0.09

$$\text{Exchanger Efficiency} = \frac{T_{co} - T_{ci}}{T_h - T_{ci}} = \frac{2 - 3}{5 - 3} = \frac{50 - 34}{58 - 34} = 0.667$$

Duct Traverse (fpm)

500	700	1200	1250	1350
750	1000	1200	1225	1350
800	1100	1150	1170	1250

$$\text{Average} = \frac{1068 \text{ fpm} \times 22 \times 16}{14 \times 16 \text{ ft}^2} = 2610 \frac{\text{ft}^3}{\text{min}}$$

$$\text{CFM} = 2610$$

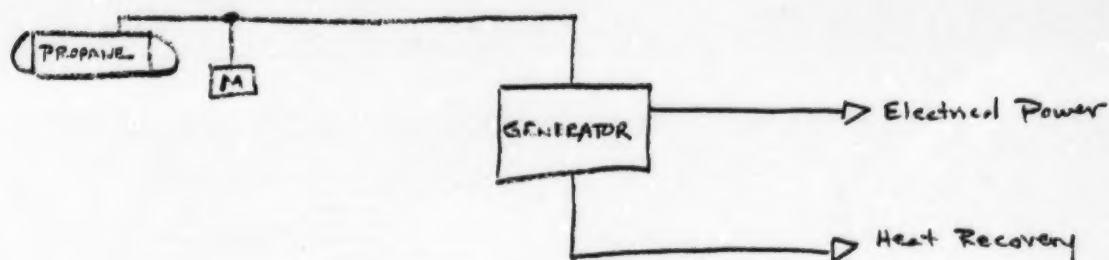
BY PLT/ASL DATE 3/28/80Wright, Pierce, Barnes & Wyman
ENGINEERS
TOPSHAM, MAINE
PORTSMOUTH, NEW HAMPSHIRE

SHEET NO. _____ OF _____

CHKD. BY _____ DATE _____

PROJECT NO. 4795PROJECT VERIFICATION DATA

BOOK NO. _____

SPECIFIC TESTSEMERGENCY GENERATOR

11:45 AM TO 12:00 NOON

	11:24	11:45	12:00	12:12
Gen. to Storage	-	204	254	
Generator Power	-	337	411	
T ₁	105	-		121
T ₄	94	-		110

$$\text{Gen. to Storage} = (254 - 204) \times 1500 \text{ Btu/ct} = 75,000 \text{ Btu}$$

$$\text{Storage Tank Heating} = (115.5 - 99.5) \times \frac{15}{48} = 5.0 \text{ F}$$

$$2000 \text{ gal} \times \frac{8.3 \text{ lb}}{\text{gal}} \times \frac{1 \text{ Btu}}{\text{lb} \cdot \text{F}} \times 5 \text{ F} = 83,000 \text{ Btu}$$

$$\text{Generator Power} = (411 - 337) \times 0.1 \text{ kWh/ct} = 7.4 \text{ kWh} \\ (25,256 \text{ Btu})$$

$$\text{Propane Usage} = 21.7 \text{ rev} \times 2 \text{ scf/rev} \times 2500 \text{ Btu/scf} = 108,500 \text{ Btu}$$

$$\text{Propane} = \text{Elect.} + \text{Recovery} + \text{Lost}$$

$$108,500 = 25,256 + 75,000 + 8244$$

$$100 = 23\% + 69\% + 8\%$$

∴ Gen to Storage and Gen. Prod. motors approx to operating normally.

WILTON - ENERGY MONITORING - 4795

5-24-79

KWH COUNTERS - MULTIPLIERS

<u>UNIT METERED</u>	<u>CT</u> <u>RATIO</u>	<u>PT</u> <u>RATIO</u>	<u>CB</u> <u>RATIO</u>	<u>FS</u> <u>WATTS</u>	<u>COUNTS</u> <u>PER HR</u>	<u>LOAD</u> <u>PH</u>	<u>Kwh/COUNT</u> <u>(MULTIPLIER)</u>
GENERATOR	60	4	240	1000	2400	240	0.1
HEAT PUMP	15	4	60	1000	600	60	0.1
D.W. HEATER	15	2	30	1000	300	30	0.1
PUMP #1	1	4	4	400	160	16	0.01
PUMP #2	1	2	4	400	160	16	0.01

WILTON ENERGY (WATTS) MONITORING 4795

	CT		PT		TRANSDUCER
	CAT. NO.	RATIO	CAT. NO.	RATIO	TRANS-DUCER
GENERATOR	631X30	300/5/1	760X3466	4/1	PIE-PCE-20
PI & P2	631X27	100/5/20	760X3466	4/1	PI-EO-(C2)*
HEAT PUMP	631X28	150/5/2	760X3466	4/1	X(0-10VDC)-F60-
D.W. HEATER	631X28	150/5/2	760X3462	2/1	WD-20-A2-G1

(C5) FOR GEN, DWH, HEAT PUMP

R PI & P2 - MULTIPLIER CALCULATIONS

STANDARD CALIBRATION - FULL SCALE WATTS - PIS WATT TRANSD.

TABLE B - PI-C2 = 200

TABLE A - PCE-20 = 2 FULL SCALE = 2X200 = 400 WATTS.

CALIBRATION ADJUSTMENT - $\pm 10\%$

ϕ INPUT 2 AMPS @ 150 VOLTS = 10VDC OUTPUT = 400VDC

OVERALL CT-PT RATIO - (20 TURNS) 100/5 - 1/1 CT 4/1 PT
= 4

$$P_{IN} = 4 \times P_{OUT} = 160 \text{ COUNTS/HR.}$$

$$P_{IN} = 4 \times 400 = 160 \text{ " / HR}$$

$$P_{IN} = 1600 \text{ WATTS} = 160 \text{ COUNTS/HR}$$

$$P_{IN} = 160 \text{ KW/HR} = 160 \text{ COUNTS OR 0.1 KW/HR} = 1 \text{ COUNT}$$

APPENDIX K

DESCRIPTION OF ANAEROBIC SLUDGE DIGESTION SYSTEM

AND

DIGESTOR GAS SYSTEM *

* From: Operation Manual, Wastewater Treatment Plant
Wilton, Maine (Volume I)

Prepared by WRIGHT-PIERCE, January, 1979

ANAEROBIC SLUDGE DIGESTION*

Description of Process

Processing the sludges that are produced and removed in a wastewater treatment plant is one of the most costly and complex tasks that the operator faces. After processing, these sludges must be disposed of in an environmentally acceptable fashion. One of the methods that has been used widely for processing organic sludges is the anaerobic digestion process. The specific objectives of anaerobic digestion include the following:

1. Decompose sludge organics to a stabilized humus.
2. Reduce the mass and volume of sludges.
3. Obtain useful by-products.
4. Destroy or control agents of disease and infection.

Nature of Sludges

Sludges processed by anaerobic digestion are derived from the primary roto-strainers and final clarifiers. Sludge solids collected on the primary rotostrainers consist mostly of larger organic and inorganic solids present in the raw wastewater. Sludge from the final clarifiers consists primarily of the organic biomass developed in the rotating biological contactor system.

The quantity of sludge solids reaching the digester depends on the removal efficiency of the sludge producing processes within the treatment plant. The removal efficiencies of processes within the plant usually are determined on a routine basis. After several months of operating experience, an operator should be able to forecast the quantities of sludge produced within the plant. Even though data on sludge quantities and characteristics are not essential for day-to-day operation, the operator should have some of this quantitative information for planning estimates and plant troubleshooting. Further discussion of sludge origin and quantities may be found elsewhere.

Digester feed sludge composition may be characterized broadly according to VS content and TS concentration. Primary screenings and RBC sludge characteristically have different TS and VS compositions. The TS concentration of the primary rotostrainers is a function of the screen opening size and operating conditions such as grease blinding. The TS concentration of the settled secondary sludge is dependent on both surface settling rate and solids detention time in secondary settling tanks. On the other hand the volatile content of both primary and secondary sludges depends on both sludge origin and its in-plant history. Biological solubilization and decomposition causes the volatile content to decrease as sludge processing time increases. The age of a sludge is usually quantified by a process parameter referred to as SRT. For a given process, it is defined as the time that a typical sludge particle resides or is retained within the process such as the RBC, final settling, or sludge holding processes.

The primary screenings have short SRT's limited to the time they spend in the raw sludge holding tank. The VS range of the screenings will vary considerably, depending on the nature of the raw wastewater. The probable range is 60 to 75 percent.

* Note: Much of this section was edited from WPCF MOP 11.

No definitive date is available on SRT for RBC sludge, but it may generally be assumed to be short (2 to 5 days). The VS of fresh RBC sludge is 72 to 84 percent. SRT in the raw sludge holding tank is a matter of hours, depending on the sludge transfer pump control timer and plant loading, so little breakdown, or solubilization, of VS will take place in the holding tank. Also, due to short residence times in all processes, temperature will remain relatively low even in summer, preventing VS solubilization. Thus, the sludge pumped to the digesters should have a high VS content, on the order of 70 - 75 percent.

Biochemistry

Successful, complete anaerobic digestion of municipal sludge is a three-stage, series reaction (Figure 5-4). In the first step, the complex organic compounds in the solid portion of feed sludge are solubilized or dissolved by enzymes that are secreted by anaerobic bacteria. These enzymes liquify a portion of the organic solids into complex soluble organic compounds. Not all of the organic solids are solubilized, however. First, some complex organic solids that can be solubilized only by a specific class of enzymes. These specific enzymes may not be present in sufficient concentrations. These are two reasons why "well digested" municipal sludges always contain residual organic matter.

Following solubilization, the complex organic molecules are converted (Figure 5-4) into simpler components by a general class of microorganisms known as the volatile acid formers. The products of the acid-forming reaction are short-chain fatty acids, primarily acetic, propionic, and butyric acid (volatile acids). Other products of the acid-forming reaction are carbon dioxide and new bacterial cells. The acid-forming steps (Figure 5-4) can proceed over a broader range of environmental conditions than the other steps.

The third and final step in the series anaerobic digestion reaction for municipal sludges is the formation of methane. Tracer studies indicate that a large fraction of this end product is formed primarily from acetic acid (Figure 5-4). The other fraction of methane produced is by decomposition of propionic and other volatile acids. It is essential that the volatile acids, which are formed in the second step of the digestion process, are converted to methane. If the volatile acids are not converted to methane, they will accumulate and ultimately lower the digester pH. This accumulation could lead to the inhibition of methane bacteria and result in process failure. Temperature, pH, ionic concentrations, and oxidation-reduction potential must be maintained within certain ranges to sustain the population of methane formers. These bacteria are more sensitive and fragile than the acid forming bacteria. Furthermore, the growth rate of methanogenic bacteria is lower than the acid forming bacteria. Therefore, it takes a longer time for the methane bacteria to recover from inhibition or shock conditions.

Combining of Stages

In the operation of Wilton's digester facilities, all three steps or stages in the series reaction, that is solubilization, acid formation, and methane formation, occur simultaneously in a given digester. If the operator would withdraw a sample of digesting sludge for chemical analysis, the result would show compounds representative of each step in the series reaction.

Some confusion exists over the meaning of the term "stage" in reference to anaerobic digestion. The Wilton wastewater treatment plant has been described as having "two stage Digestion". What is really meant is that a quantity of feed sludge is routed through two digesters connected in series. The sludge is initially fed to a heated digester in which it undergoes solubilization, acid formation, and methane formation. The nominal residence time in the first digester is 14 days at design flow. Digested sludge is then transferred to a second digester that has the same configuration as the first tank. In the second tank, approximately 2 to 10 percent of the original biodegradable organics may still be solubilized and converted into volatile acids and finally methane. The principal function of the second digester, however, is to provide quiescent conditions for separation of solids and supernatant removal. Instead of "two stage digestion", the operator should use the terms "primary-secondary digestion".

Completely Mixed Digestion

In conjunction with primary-secondary digestion, Wilton utilizes complete mixing in the primary tank. In a completely mixed tank or reactor, the materials flowing into the tank are instantaneously mixed or diluted throughout the entire tank. At any instant of time, the composition of a sample taken from the tank effluent would be identical to that of a sample taken anywhere in the tank.

A completely mixed digester operating mode offers several significant advantages over an unmixed system. These include:

1. Very quick dilution and dispersion of incoming raw sludge is achieved, thereby decreasing the likelihood of toxicity, inhibition, or thermal shock problems. Inhibitory by-products of the digestion process are likewise dispersed.
2. Buffering alkalinity is distributed throughout the tank, thus aiding pH control.
3. Intimate food (sludge) to mass (anaerobic microorganisms) contact is attained.
4. Smaller safety factors in reaction design (due to non-uniform flow, solids concentration, and chemical composition of raw sludge) are required.
5. Grit and other nondegradable particles are kept in suspension, significantly decreasing deposition and accumulation of debris.
6. Scum is kept in suspension, preventing the buildup of a thick scum blanket which may significantly decrease useable digester volume.
7. Uniform temperatures are maintained throughout the reactor.

Reduction of Volatile Matter

One of the main objectives of anaerobic digestion is the decomposition or reduction of the organic fraction of digester feed sludge. In sludge analysis, the organic fraction is estimated by determining the volatile content of the sludge. The operator must bear in mind, however, that a standard VS analysis measures both biodegradable organics and the organic materials that will not decompose during anaerobic digestion. Unlike aerobic processes, such as the activated sludge process in which 80 to 98 percent of the dissolved volatile material is removed, VS reduction in an anaerobic digester is substantially lower. Even in the case of a well-operated digester, a VS reduction in excess of 60 to 79 percent is unlikely.

The reduction of VS by anaerobic digestion may vary considerably from digester to digester. Moreover, the amount of VS reduction obtained within a given digester is dependent on a number of variables. One of the most important variables is the raw sludge composition. Some sludges contain materials such as cellulose that are solubilized at a very slow rate. Once solubilized, however, the complex organics generally will decompose. As a result, the rate of solubilization may limit the degree of VS reduction.

Another characteristic of the VS reduction calculation is that its value fluctuates from day to day. Fluctuations are caused by changes in volatile content of the feed sludge, by sharp changes in sludge loading rate, and by changes in reactor conditions such as mixing or temperature. If VS reduction is calculated, it should be based on a monthly average and not on daily values. The VS reduction in a digester is highly dependent on the initial VS composition of the raw sludge. All other things being equal, a raw sludge with a volatile content of 75 percent will have a significantly larger VS reduction than a raw sludge having a 65 percent VS concentration.

Care must be taken in the use of VS reduction data. It may be useful for assessing the relative performance of a given digester facility. It is unrealistic to expect digesters from several different municipalities to achieve the same percentage reduction of volatile content, however. Each facility will vary. If it is desired to establish whether a sludge is adequately digested, a more rational criterion based on the degree of gasification achieved is preferred. Digestion may be considered complete if 90 to 95 percent of total gasification has been achieved.

Organic Loading

One of the fundamental design and operational parameters of biological treatment processes is the rate of substrate or food addition per unit mass of microorganisms. This is called the organic loading rate, OLR. In activated sludge processes, the organic loading rate is expressed as the F:M ratio or process loading intensity in units of pounds of organic material (expressed as BOD, COD or TOC) per pound of MLVSS per day.

MLVSS is a convenient approximation of the relative concentration of microorganisms in the activated sludge process. Unfortunately, there is no equivalent analysis for estimating the microbial population in an anaerobic digester. Anaerobic bacterial solids cannot be separated from the digesting organic sludge solids. Nevertheless, an organic loading rate approximation may be made because the actual concentration of methanogenic organisms in a digester changes quite slowly. Therefore, if the weight of organisms in a volume of digester is relatively constant, the organic loading rate for the digester may be expressed as the weight of organic or volatile feed sludge solids added per volume of digester per day, for example, lb VS/day/cu ft.

The organic loading rate is significant because it influences the rate of gas production and the stability of the anaerobic digestion process. The volume of gas produced from each pound of VS destroyed will range from 10 to 18 cu ft. Furthermore, the rate of gas production is nearly proportional to the rate of

organic loading. This is true for both the average 24-h loading rate and the instantaneous loading rate. Problems may arise when digesters are loaded with quantities of organic solids on an infrequent basis, for example, only once a day. In this situation, gas production rate may be so vigorous that severe foaming may result.

Digester operating temperature is the criterion used to classify a digester as being mesophilic or thermophilic. Mesophilic indicates that the digester's nominal operating temperature falls in the range of 80° to 100°F. The thermophilic range is 110° to 140°F. Wilton's digesters are designed to operate in the mesophilic range, at 95°F. The operator should experiment with various temperatures in the mesophilic range to determine the temperature that is best for Wilton's digesters. Once the optimum temperature is found the primary digester should be maintained as closely as possible to that temperature.

Sludge withdrawn after 90 percent of the available gas has been produced will not create a nuisance. Most of the VS that will decompose readily are solubilized within a matter of hours or a few days. The remainder of the volatile material is solubilized and converted at a much slower rate. Therefore, the organic solids remaining in the sludge after withdrawal will continue to break down at a rate similar to the slow rate at which organic decay occurs in forests. Solubilized, complex organics in the sludge withdrawn from a digester still may be converted to methane if anaerobic conditions prevail. On the other hand, they may be oxidized to CO₂ and water in an air or oxygen environment. In either case, the nuisance intermediates, that is, volatile acids, H₂S, mercaptans, amines, will not be present in sufficient concentrations to create a major problem.

Gas Production

Gas production is one of the most important measurable digestion parameters. The total volume, rate, and composition of gas produced are indicative of a digester's performance. The total volume of gas produced, assuming that the feed sludge composition remains constant, is a measure of the degree of reaction in the digester. The number of cubic feet of gas produced per pound of VS entering the tank should be calculated by the operator. The results should be charted for a number of months to characterize digester performance. Once characterized according to gas production per pound of solids destroyed daily, determinations may be made and compared with the long-term value previously calculated. Deviation from the norm may be indicative of a change in the extent of digestion or a change in the character of the VS being fed.

Gas production rate and gas composition also provide information about digester performance. The rate of gas production should be measured on the digester gas line from each digester. Composition is determined by an Orsat analyzer.

Several months of operating experience should indicate the rate of gas production to be expected from the addition of a known quantity of volatile sludge solids. If the rate of gas production begins to fall below the expected level, then careful surveillance of the process should be initiated to assess the cause and protect against ultimate digester failure. Gas composition, like gas production rate, is also a useful gauge for determining the state of a digester.

Digester stability may be affected by excessive organic loading rates. This is true for both the average 24-h loading rate and the instantaneous loading rate. Excessive organic loading rates may yield a rapid build-up of short-chain fatty acids, also referred to as total volatile acids, that may inhibit the methane-forming organisms.

Organic loading rate is a key parameter used to characterize the two different modes of municipal digester design and operation. These two modes are referred to as standard rate digestion and high rate digestion.

Standard Rate and High Rate Digesters

As digester design evolved to include heated, closed tanks with gas collection capabilities, operating experience indicated that the organic loading rate should be maintained between 0.03 and 0.01 lb VS/day/cu ft. The section of a standard rate digester in which active digestion occurs is only a portion of the total digester volume. Because standard rate digestion does not incorporate sludge mixing, the digester is stratified into zones, thus severely reducing the effective volume of the tank.

Wilton's digesters are designed for high rate digestion. High-rate digestion evolved from design and operating improvements made to the original standard rate digester. Mixing capability was added to digester designs, thus providing homogeneity throughout the tank. Sludge feeding and withdrawal were provided on a continuous or nearly continuous basis. Furthermore, improvements in heating equipment yield a more uniform distribution of temperature throughout the reactor. As a result of these improvements, plant operating experience has indicated that an organic loading rate of 0.1 to 0.4 lb VS/day/cu ft may be used for high-rate digestion.

The high-rate and standard rate terminology, which has been used for years, is somewhat deceptive. The terms do not mean that the rate at which solid organic materials are converted to methane is faster in a high-rate digester than in a standard rate digester. Actually, the chemical reaction rate constant is the same in both digesters, provided the temperature is identical. The high-rate design provides conditions that are more favorable to anaerobic digestion, however.

Mixing, improved heating, and the more continuous feed that characterize high-rate digesters provide a more complete interaction of the microorganisms and the organic sludge materials. Therefore, it should be remembered that high rate refers to the higher organic loading rate rather than the rate of conversion from solids to methane.

Time and Temperature

In general, the detention time needed to obtain complete digestion decreases with increasing temperature. In the field, however, a temperature change of ± 5

Because the most important end product of anaerobic decomposition is methane, the methane concentration in the gas usually indicates whether the anaerobic reactions have gone to completion. If the methane fraction of the gas begins to decrease, then the series reaction (Figure 5-4) is probably not going to completion, and the digester eventually will fail unless some corrective measures are taken.

Description of Facilities

Tank Construction

The two digesters in Wilton are identical in construction. They are cylindrical, 20 ft. in diameter by 17 ft. deep at the sides with conical floors sloping 4:1 to a center well. They are constructed of reinforced cast-in-place concrete. The walls are 1 ft. thick. Fixed steel dome-shaped covers are provided for each digester.

Because the digesters must be heated, they are well insulated. The perimeter is insulated with 1 3/4 inch rigid styrofoam and is faced with brick. The tanks are mostly below grade to take advantage of the insulating value of the earth. The roofs are insulated with 2 inches of urethane and covered with 4-ply built up roofing.

The digester control room is located between and north of the digesters. Its two levels contain the appurtenant equipment.

Digestion and Solids Separation Tanks

Although solids destruction and stabilization are the primary functions of municipal digestion facilities, there is also a secondary function. Normally, the solids remaining in the digested sludge must be concentrated for subsequent treatment or disposal. This operation is referred to as solid-liquid phase separation.

As a result, most municipalities that use high-rate digestion require some type of solid-liquid separation unit. The separation unit is the secondary digester which is physically identical to the primary digester. Because of the vigorous gasification and supplemental mixing in a high-rate digester, the excess gas dissolved within the sludge (mostly CO_2) tends to keep the digested sludge particles suspended. Thus, gravity separation of supernatant and solids can be a slow process.

Besides solid-liquid separation, facilities usually are provided for temporary storage of concentrated digested sludge. The digested sludge holding tank lies between the digester control room and the clarifier room. Its function is to store digested sludge which is periodically transferred to it until such time as a sufficient quantity is accumulated to dewater.

Digester Covers

Wilton's digesters are provided with fixed steel covers. They are equipped with a positive displacement feed and drawoff arrangement because it is essential that the volume of new sludge added to the digester equals the volume removed. Otherwise, a negative gas pressure may develop under the cover, thus allowing atmospheric air to enter. In certain concentrations, oxygen mixed with methane may produce an explosive atmosphere. The low and high explosive

limits of methane in air are 5.3 and 14.0 percent, respectively. This means that when the volume ratio of CH_4 :air is greater than 5.3 percent and less than 14 percent an explosive situation exists. Because "pockets" or localized concentrations of CH_4 may exist, extreme care should be exercised whenever methane exists in any amounts.

Heating

Raw sludge is fed directly to the primary digester. Mixed sludge from the primary digester is recirculated through the digester heat exchanger where the digester calls for heat. The last exchange is a Don Oliver flow sludge heater, located in the eastern end of the lower level digester room.

Mixing

Mixing is also a very important part of high-rate digestion. A firm definition of "adequate mixing" is not known, but operating experience indicates that mixing at least equivalent to pumped recirculation of the entire contents of the tank over a period of 12 to 24 hours is recommended.

Pumps

Two centrifugal pumps located in the lower digester room are used for all internal digester sludge transfer functions.

Piping

Sludge piping is generally fiberglass reinforced plastic (FRP).

Safety Equipment

Digester gas is a potential safety hazard. The following safety equipment is provided at Wilton:

1. Pressure relief, vacuum relief, and flare traps;
2. Waste gas flare trap;
3. Flare traps on all gas-utilizing equipment lines;
4. Drip traps;
5. Outside vented lines from gas equipment;
6. Explosive gas detectors.

APPENDIX L

Shading Coefficient due to Overhang of Passive Collector Array

January	1.00
February	0.97
March	0.96
April	0.94
May	0.87
June	0.86
July	0.87
August	0.93
September	0.96
October	0.97
November	1.00
December	1.00

APPENDIX M

Active Solar Specification Data

The active solar collectors were specified as follows:

Quantity	54	
Gross Area	27.75 ft ²	1498 ft ²
Aperture	23.82 ft	1286 ft ²
Number of glazing lites		2
Glazing thickness		3/16 inch
Type	Tempered	
Transmissivity		90.5%/Sheet
Insulation	Fiberglass R-22	
	(changed to 5" ISOSYANURATE R-40)	
Water	- glycol solution 50/50	
Solution temperature	120°F - 140°F	

Efficiency determined by a straight line passing
thru 58% at T/I of .2
and 33% at T/I of .6
for a clear day

$$\text{Efficiency} = \frac{Q \text{ heat removed from panel by fluid}}{\text{panel effective ft}^2 \times \text{solar Insolation}}$$

$$\text{Solar insolation} = I \text{ (BTU/Hr - ft}^2\text{)}$$

$$\begin{aligned} Q \text{ heat removed} &= W \times C_p \times (T_{\text{out}} - T_{\text{in}}) \\ &= \text{Flow rate} \times \text{specific heat} \times DT \end{aligned}$$

$$\text{Effective area} = \text{Aperature}$$

$$T \text{ fluid avg.} = \frac{T_{\text{out}} - T_{\text{in}}}{2} \text{ } ^\circ\text{F}$$

Insulation/site data includes:

45° Latitude North

60° Tilt angle

Collector facing 5° West of South

Monthly Average Ambient Temperatures

Jan.	24°F	Jul.	71°F
Feb.	25°F	Aug.	70°F
Mar.	35°F	Sept	62°F
Apr.	45°F	Oct.	54°F
May	56°F	Nov.	41°F
June	65°F	Dec.	28°F

5 MPH wind speed